APTD-1496

APRIL 1974

EXHAUST EMISSIONS FROM UNCONTROLLED VEHICLES AND RELATED EQUIPMENT USING INTERNAL COMBUSTION ENGINES: PART 7 - SNOWMOBILES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

APTD-1496

EXHAUST EMISSIONS FROM UNCONTROLLED VEHICLES AND RELATED EQUIPMENT USING INTERNAL COMBUSTION ENGINES: PART 7 - SNOWMOBILES

by

Charles T. Hare and Karl J. Springer

Southwest Research Institute
San Antonio, Texas

Contract No. EHS 70-108

EPA Project Officer: William Rogers Oliver

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control Programs
Emission Control Technology Division
Ann Arbor, Michigan 48105

April 1974

Publication No. APTD-1496

ABSTRACT

This report is Part 7 of the Final Report on "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Contract EHS 70-108. Exhaust emissions from four snowmobile engines were measured using steady-state "mapping" procedures, employing 29 combinations of speed and load for each engine. The engines tested were an Arctic 440, a Polaris 335, a Rotax 248, and an OMC 528 rotary. The first three engines listed are all 2-stroke vertical twins with blower cooling, and the last engine is a blower- (and charge-) cooled rotary combustion (Wankel) engine.

The procedures used for operation of snowmobile engines included idling and a variety of engine loads at four to six crankshaft speeds, depending on the engine. The gaseous exhaust constituents measured on a continuous basis during all the test modes included total hydrocarbons by FIA; CO, CO_2, NO, and HC by NDIR; NO and NO_x by chemiluminescence; and O_2 by electrochemical analysis. Gaseous constituents measured during some modes on a bag sample or grab sample basis included light hydrocarbons by gas chromatograph, and formaldehyde (HCHO) and total aliphatic aldehydes (RCHO) by wet chemistry. Exhaust smoke was measured using a PHS full-flow smokemeter, and exhaust particulate was measured using an experimental dilution-type particulate sampler. The smoke and particulate measurements were acquired only at a limited number of conditions selected from the 29 speed/load combinations used for gaseous emissions testing.

The engines were operated on a special test stand, utilizing a small water-brake dynamometer and inlet air controlled to a nominal 20°F. The emissions results are used in conjunction with available data on snowmobile population and usage to estimate national emissions impact.

FOREWORD

The project for which this report constitutes part of the end product was initiated jointly on June 29, 1970 by the Division of Motor Vehicle Research and Development and the Division of Air Quality and Emission Data, both divisions of the agency known as NAPCA. Currently, these offices are the Emission Characterization and Control Development Branch of MSAPC and the National Air Data Branch of OAQPS, respectively, Office of Air and Water Programs, Environmental Protection Agency. The contract number is EHS 70-108, and the project is identified within Southwest Research Institute as 11-2869-001.

This report (Part 7) covers the snowmobile portion of the characterization work only, and the other items in the characterization work have been covered by six other parts of the final report. In the order in which the final reports have been submitted, the seven parts of the characterization work include: Locomotives and Marine Counterparts; Outboard Motors; Motorcycles; Small Utility Engines; Farm, Construction and Industrial Engines; Gas Turbine "peaking" Powerplants; and Snowmobiles. Other efforts which have been conducted as separate phases of Contract EHS 70-108 include: measurement of gaseous emissions from a number of aircraft turbine engines, measurements of crankcase drainage from a number of outboard motors, and investigation of emissions control technology for locomotive diesel engines; and those phases either have been or will be reported separately.

Cognizant technical personnel for the Environmental Protection Agency are currently Messrs. William Rogers Oliver and David S. Kircher; and past Project Officers include Messrs. J. L. Raney, A. J. Hoffman, B. D. McNutt, and G. J. Kennedy. Project Manager for Southwest Research Institute has been Mr. Karl J Springer, and Mr. Charles T. Hare has carried the technical responsibility.

The offices of the sponsoring agency (EPA) are located at 2565 Plymouth Road, Ann Arbor, Michigan 48105 and at Research Triangle Park, North Carolina 27711; and the contractor (SwRI) is located at 8500 Culebra Road, San Antonio, Texas 78284.

The assistance of several groups and individuals has contributed to the success of the snowmobile portion of this project, and it should be acknowledged. Appreciation is first expressed to the International Snowmobile Industry Association (ISIA), in particular to Mr. John F. Nesbitt, who supplied population, sales, and usage data gathered by ISIA from its member companies. Thanks are also expressed to Sally Wimer, editor of Invitation to Snowmobiling magazine for her interest in the snowmobile studies and her assistance over a period of two years or more, and to Snow Goer Trade magazine for back issues containing material of interest to this study. Appreciation is also expressed to the corporations which supplied engines for testing and to technical personnel at these companies who gave invaluable assistance, namely: Arctic Enterprises, Inc., and Messrs. Wayne Konickson and Ron Solberg; Bombardier, Ltd., M. Zoel Bergeron; Outboard Marine Corporation, and Messrs. Mike Griffith and George Miller; and Polaris Industries, Mr. Les Foster. Mr. Lowell Haas of Scorpion, Inc. also assisted with comments on test procedures and technical details.

The SwRI personnel who performed most of the preparation and test work included: Russel T. Mack, lead technician; William P. Jack, Paul Fowler, Ernest Krueger and Nathan Reeh, technicians; and Joyce Winfield, laboratory assistant. The contributions of all these people are sincerely appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

I. INTRODUCTION

The program of research on which this report is based was initiated by the Environmental Protection Agency to (1) characterize emissions from a broad range of internal combustion engines in order to accurately set priorities for future control, as required and (2) assist in developing more inclusive national and regional air pollution inventories. This document, which is Part 7 of a seven-part final report, concerns emissions from snowmobiles and the national impact of these emissions.

Prior to the subject work, virtually no useful information on snowmobile emissions had been published. Although a great many papers were available on emissions from 2-stroke engines, they were concerned with either engine modifications to reduce emissions or with engines of sizes and types other than those commonly used in snowmobiles. The procedures used to acquire emissions data for this report were chosen with the intent of gathering the most useful results, but little consideration has been given to the potential usefulness of these procedures for anything except research purposes. All the subject tests were performed in the SwRI Emissions Research Laboratory between March 19 and July 31, 1973.

II. OBJECTIVES

The objectives of the snowmobile part of this project were to obtain exhaust emissions data on a variety of engines and to use these data in conjunction with available information on a number of snowmobiles in service and their annual usage to estimate emission factors and national impact. The emissions to be measured included total hydrocarbons by FIA; CO, CO_2, NO, and HC by NDIR; O_2 by electrochemical analysis; light hydrocarbons by gas chromatograph; aldehydes by wet chemistry; particulates by gravimetric analysis; and smoke by the PHS light-extinction smokemeter. These exhaust constituents are essentially the same as those measured during all tests on gasoline-fueled engines tested under this contract.

The objectives included implicitly the development of test procedures suitable for obtaining emissions data on snowmobile engines and the development or modification of calculation techniques for emission factors and national impact. It was also necessary to simulate the snowmobile's operating environment to some extent, and to this end a system was constructed to provide air to the carburetor at a nominal 20°F and at normal atmospheric pressure.

III. TEST DOCUMENTATION, INSTRUMENTATION, PROCEDURES, AND CALCULATIONS

This report section includes descriptions and photographs of the test engines, descriptions and photographs of the test equipment and instrumentation used, and explanations of the test sequences and calculation methods employed. Briefly, four engines were tested using a small water-brake dynamometer and state-of-the-art emissions measuring equipment; and the engines were supplied with intake air at or near 20° F to help simulate field operation. Three of the engines were 2-stroke twins, representative of the majority of newer engines in service, and the fourth was a rotary (Wankel) engine which was chosen due to mechanical novelty and anticipation of future engine trends. The testing procedures used included three modes at idle plus 28 other speed/load conditions which were intended to span the operating range of the engines. These 28 conditions were not uniform from engine to engine due to different rpm ranges and power bandwidths.

A. Engine Specifications and Descriptions

To show the extent to which the engines tested were representative of those currently being offered, Table 1 has been prepared to show the major specifications of the test engines as compared to approximate industry ranges for the 1972-1973 models. It appears that the test engines generally fell in the center of the power plants available according to most design criteria, which was one of the main objectives of choosing these engines. The exception to this rule is the OMC rotary, which was included in the test program primarily to assess possible future changes in snowmobile emissions rather than to help determine current national impact. In terms of the results of a snowmobile ownership survey (1972-1973 season)[(1)*], the three brands in most widespread use were Ski-Doo (Bombardier), Arctic Cat, and Polaris, represented by the three reciprocating engines tested. The 2-stroke engine has become almost the universal snowmobile powerplant (until the advent of the rotaries) due to its relatively high power/weight and power/size ratios, low cost, minimum number of moving parts, and extremely good cold weather starting capability.

B. Test Documentation and Equipment

Photographs of the test engines begin with Figure 1, which shows the Arctic Cat 440 engine (manufactured by Kawasaki) mounted on a

---

* Superscript numbers in parentheses refer to the List of References at the end of this report.

TABLE 1. SPECIFICATIONS OF TEST ENGINES COMPARED TO APPROXIMATE INDUSTRY RANGES* FOR THE 1972-1973 MODEL YEAR

Specification	Artic 440	Polaris Star 335	Bombardier (Rotax) 248	OMC 528 Rotary	Industry Range
Displacement, cm^3	436	335	247	528	225-560
Cylinders	2	2	2	(1 rotor)	1-3
Rated Power, hp	32[(a)]	25	16	35	12-58[(b)]
Rated rpm	7000	6500	6000	6000	5500-8000[(c)]
Induction	piston port	piston port	piston port	(d)	(e)
Cooling	Air-Axial Blower	Air-Radial Blower	Air-Axial Blower	Air-Radial Blower[(f)]	Air, Liquid, and Charge
Compression Ratio	6.8	6.7	6.7	8.5	6.5-6.8[(g)]
Rated hp/liter	73	77	65	66	49-116[(h)]

* Do not include mini-snowmobiles or over-the-counter racers--see notes b, c, and g
(a) Not from manufacturer's data
(b) Conventional engines only--mini-snowmobiles down to 3 hp, racers up to 124 hp
(c) Conventional engines only--mini-snowmobiles down to 3600 rpm, racers up to 9500 rpm
(d) Side and Peripheral ports
(e) Piston port, reed valve, and rotary valve for 2-strokes
(f) Plus charge cooling of rotor
(g) 2-stroke engines only
(h) Conventional engines only-- mini-snowmobiles down to 18, liquid-cooled up to 114, racers up to 190

stand constructed especially for these tests. The stand was made of steel channel and angle, with a great deal of reinforcement; and the engines were mounted on a 1/2-inch steel plate which was attached to the stand proper using resilient mounts. In some cases, the severity of vibration created by the engines required that the mounting plate be damped by sections of angle bolted to it and the main frame.

The power absorption unit of the Stuska 90 hp water-brake dynamometer is partially visible behind the engine in Figure 1. This photo also shows a typical adaptation to the stock exhaust system made for test purposes with the (stock) short cylindrical section exiting the muffler at a right angle and immediately "dumping" into a 4-inch diameter duct. The general approach taken was to allow the exhaust to enter as large a duct as possible as it came out its normal opening, and to allow the intake air to be drawn into its normal entrance (either the carburetor(s),

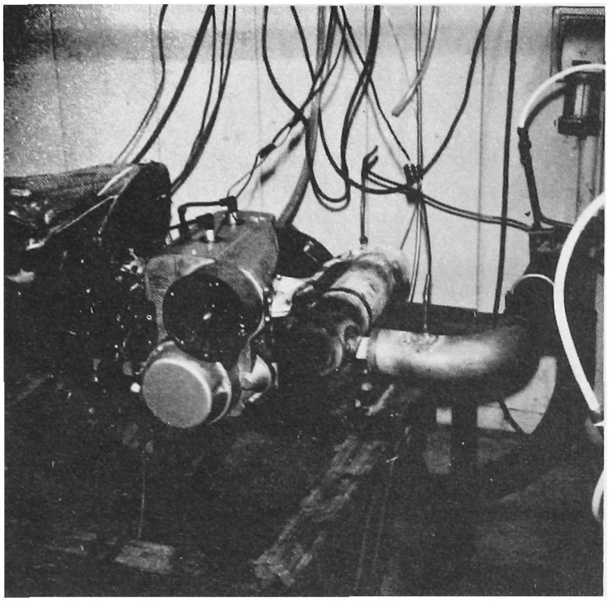

FIGURE 1. ARCTIC CAT 440 ENGINE ON TEST STAND

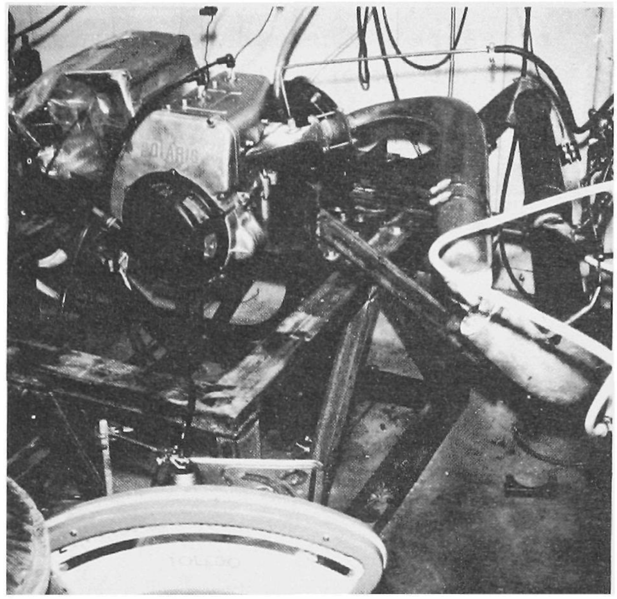

FIGURE 2. POLARIS 335 ENGINE ON TEST STAND

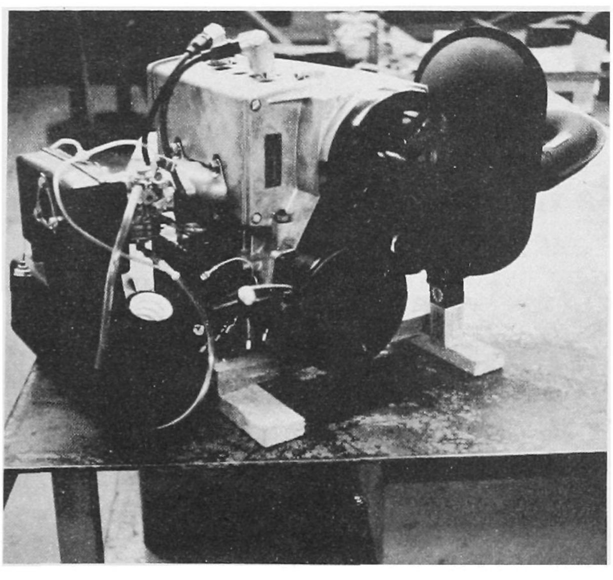

FIGURE 3. BOMBARDIER (ROTAX) 248 ENGINE (PHOTO SUPPLIED BY BOMBARDIER)

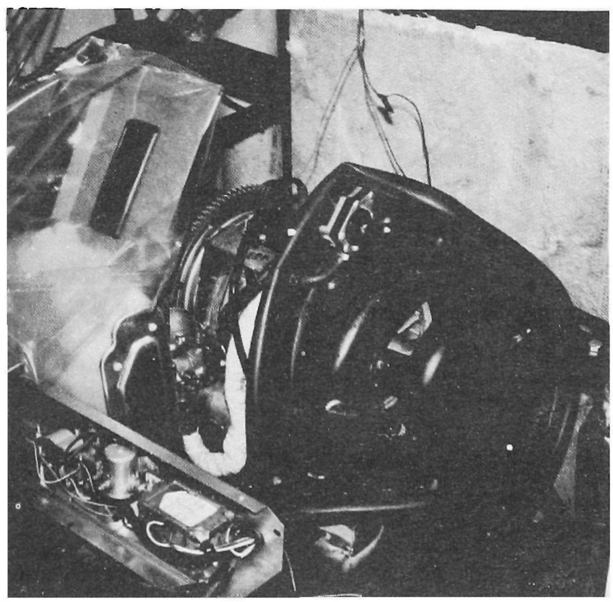

FIGURE 4. OMC 528 ROTARY ENGINE ON TEST STAND

silencer, or filter) from as large a volume as possible at atmospheric pressure. The exhaust systems permitted pressures at the normal exhaust outlet within 0.1 inch Hg above atmospheric pressure.

Figure 2 shows the Polaris 335 engine, and the scale used to determine fuel mass flow rate appears in the foreground. Fuel for all the engines was equivalent to Federal emission test gasoline[(2)], plus the recommended amount of lubricant as specified by each engine manufacturer. The fuel was drawn from a 5-gallon container on one side of the scale, and balance weights were added to the other side to bring the imbalance within the 0-2 lb_f range of the scale (readout in 0.01 lb_f increments). Fuel times were taken with a stopwatch while the engines consumed a predetermined amount of fuel, the amount varying according to rate of consumption to keep the time measurements to reasonable lengths.

Figure 3 shows the Bombardier (Rotax) 248 engine (this photo was supplied by Bombardier), and Figure 4 shows the OMC 528 rotary. Note in Figure 4 that the stock air inlet grille is mounted in a flat surface and that a Tedlar* plastic enclosure is used to duct intake air from the cooling chamber to the grille. These flexible plastic ducts, having a relatively large volume and no solid boundaries when the inlet air was at atmospheric pressure, were used to prevent unwanted pulsations at the intake point. The insulating panel shown beside the engine in Figure 4 can be located more precisely by referring to Figure 5, which shows it to be located between the engine and muffler to prevent radiant transfer of heat from muffler to engine. The square duct at the foreground in Figure 5 is the outlet of a high-volume blower used to cool the muffler on this engine, since the engine produces extremely high-temperature exhaust gases.

Figure 6 shows more detail of the plastic intake duct used on the Polaris 335 engine, which is also similar to those used on the others. Some detail of the intake air cooling system is shown in Figure 7, with the barrel on the left containing a naphtha-type liquid in which were immersed chunks of dry ice to keep its temperature down to about -75°C. This cold liquid was pumped through three concentric coils of 1/2-inch diameter copper tubing mounted in the other barrel, totalling about 250 feet in length. Room air at about 75°F was supplied to the second barrel (at right in Figure 7) by the blower in the foreground, and it circulated over the coils through a system of baffles. Pressure at the engine air inlet was monitored by the water manometer mounted on the right-hand barrel and was controlled to within 0.1 inch H_2O above atmospheric pressure by restricting the make up blower inlet and adjustment of the counterweighted waste-gate on the top of the right-hand barrel.

---

* Registered trademark of E. I. duPont De Nemours & Company

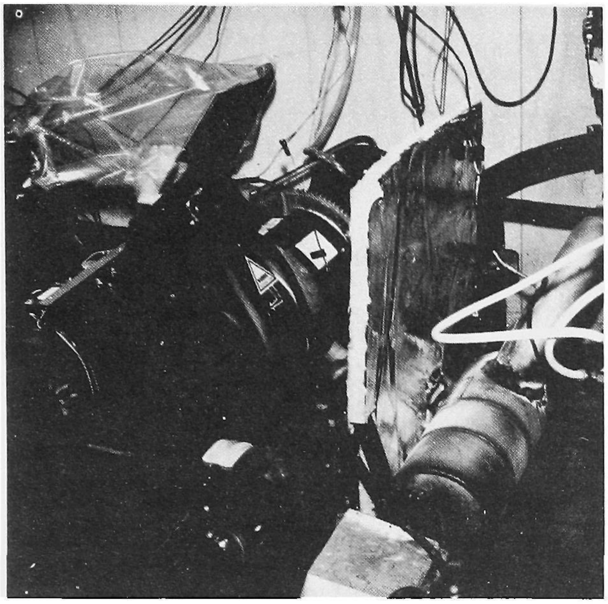

FIGURE 5. DETAILS OF EXHAUST SYSTEM USED ON OMC 528 ROTARY ENGINE

FIGURE 6. DETAILS OF PLASTIC INTAKE DUCT USED ON POLARIS 335 ENGINE (TYPICAL OF THOSE USED ON ALL FOUR ENGINES)

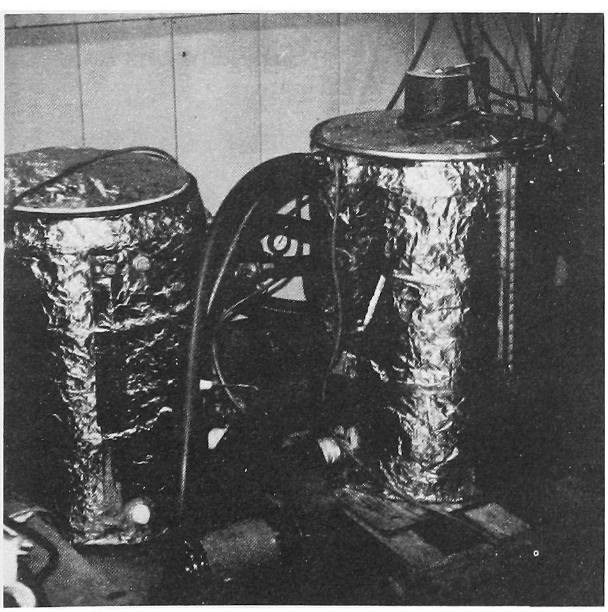

FIGURE 7. DETAILS OF INTAKE AIR COOLING SYSTEM

FIGURE 8. OVERALL VIEW OF EQUIPMENT AND PERSONNEL DURING A TEST

Samples of exhaust for continuous analysis as well as batch samples were withdrawn from the fabricated, large-diameter exhaust pipe at a point from 2 to 3 feet downstream of the original muffler outlet. The sample taps are shown quite clearly in Figure 2 along with a thermocouple inserted nearer the muffler outlet, and they also appear at the extreme left of Figure 8. Figure 8 shows the test layout quite well, including the sampling cart operator (right), the engine operator, and another technician to take fuel time measurements. Continuous exhaust samples were piped to the main gaseous emissions cart via an overhead sample line, but the samples for the FIA hydrocarbon analyzer and for aldehyde analysis were taken through a short, heated line right next to the exhaust pipe. The proximity of the FIA analyzer's detector unit (the box-shaped unit in the right background) to the exhaust line can be seen in Figure 9, and the glass bubblers on the side of the oven away from the engine were the ones used to collect samples for aldehyde analysis. Figure 9 also shows the fuel scale in more detail, as well as the row of ice-bath water traps (in front of the FIA) used to dry the samples going to all the analyses except those for aldehydes and hydrocarbons by FIA. The gauges on the wall in the background of Figure 9 are a tachometer and a load indicator for the dynamometer.

The continuous exhaust samples were analyzed for total hydrocarbons by FIA (at 160°F) and for (mostly paraffinic) hydrocarbons by NDIR. They were also analyzed for CO, CO_2, and NO by NDIR; for NO and NO_x by chemiluminescence; and for O_2 by an electrochemical analyzer. Samples taken by bubbling exhaust through reagents for a specific time interval were analyzed for formaldehyde (HCHO) by the chromotropic acid method[3] and for total aliphatic aldehydes (RCHO) by the MBTH method[4]. Bag samples were used for light hydrocarbon analysis (methane through butane, total of seven compounds). The chromatograph employed a 10 foot by 1/8 inch column packed with a mixture of phenyl isocyanate and Porasil C, preceded by a 1 inch by 1/8 inch pre-column packed with 100-120 mesh Porapak N.

In addition to the gaseous emissions, particulates and smoke emitted by the snowmobile engines were also studied. Figure 10 shows the system used to deliver exhaust gases to the particulate sampler for the Polaris engine, which was typical of the systems used for the other engines also. For particulate and smoke measurements, the exhaust pipes were necked down to a 2-inch diameter at a point several feet downstream of the standard muffler outlet. This change from the system used for gaseous emissions sampling had a negligible effect on exhaust backpressure, and it was necessary to provide exhaust gases in the correct range of velocities for the particulate sampler. The sampler operated by diluting and cooling a small stream of raw exhaust with clean air, filtering the mixture, and providing flow measurements so that particulate concentrations could be calculated. The sampler was experimental and was developed under this contract for research purposes only. The 2-inch diameter outlet for smoke

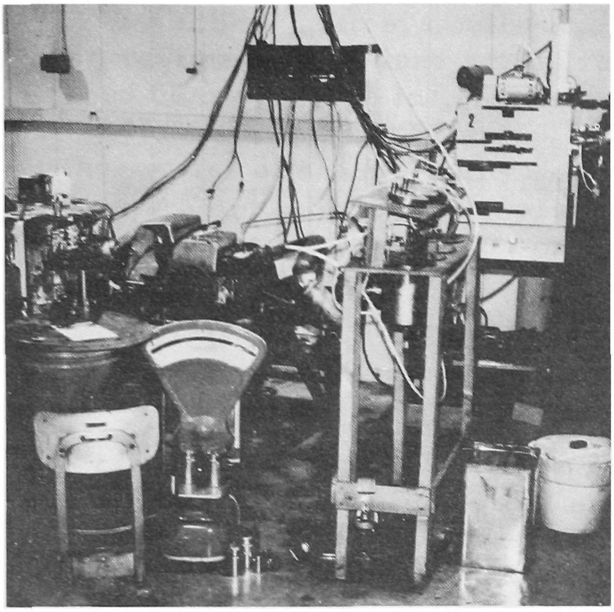

FIGURE 9. DETAILS OF FUEL SCALE, WATER TRAPS, FIA DETECTOR UNIT, AND DYNAMOMETER READOUTS

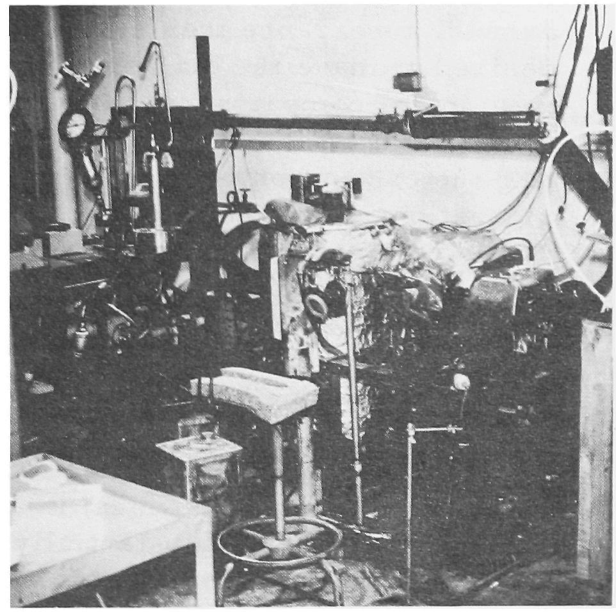

FIGURE 10. TYPICAL SETUP FOR PARTICULATE SAMPLING

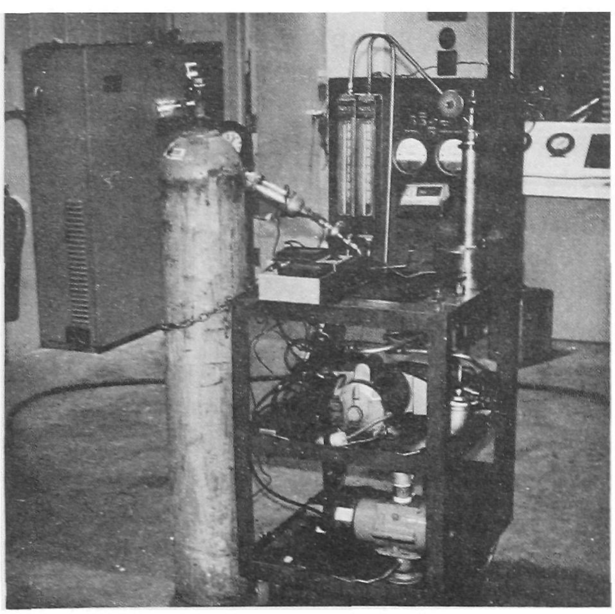

FIGURE 11. DETAILS OF EXPERIMENTAL PARTICULATE SAMPLER

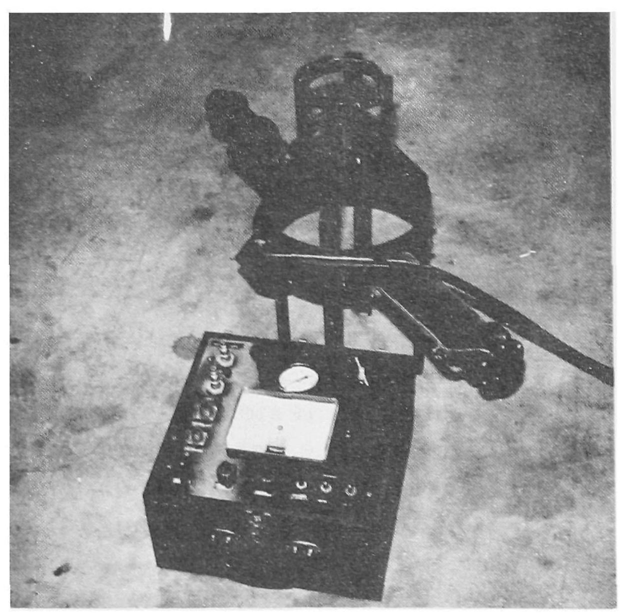

FIGURE 12. DETAILS OF PHS SMOKEMETER

measurements was also thought to be more representative of "real" exhaust appearance than something larger would have been, and it was desired to make the diameter uniform for all the engines to permit meaningful comparisons. The optimum situation, of course, would be to measure smoke at the standard muffler outlet; but this approach (letting the exhaust out into the test area) was impractical due to safety considerations. The smoke measurements were taken outside on a 2-inch diameter pipe protruding through the wall to circumvent the safety problem. Details of the experimental particulate sampler are shown in Figure 11, and a PHS smokemeter[5] of the type used is shown in Figure 12.

C. Emissions Test Procedures

It was initially planned to operate each of the engines at idle, plus (seven loads x 4 speeds) in a uniform "map" of conditions. This procedure was used substantially intact for testing the Arctic Cat 440 (the first engine tested), but it was revised to include more speeds and fewer loads at some of the speeds (to keep the total number of test modes constant) as understanding of snowmobile operation matured. A summary of the actual speed/load conditions used for gaseous emissions sampling is given in Table 2, with the conditions used for light hydrocarbon and aldehyde sampling indicated; those used for particulate sampling indicated, and those used for smoke measurements also indicated. Time simply did not permit a greater number of modes to be used for tests other than gaseous emissions sampling. It should be noted also that smoke data were acquired under several conditions not used for gaseous emissions tests, namely 3000 rpm/full load for the Rotax and 2500 rpm/full load and 2500 rpm/1/2 load for the Polaris.

Time requirement in each mode of these procedures was dictated by a combination of sampling time (for batch samples), time for the engine to consume a predetermined amount of fuel, and stability of emission levels (for constituents measured on a continuous basis). The samples for aldehyde and light hydrocarbon analysis were acquired concurrently with the continuous gaseous emissions tests, but both the particulate and the smoke tests required individual runs.

All the test conditions were steady-state, and no attempt was made to obtain numerical data during transient conditions. Observation of the continuous recorder charts, however, indicated that excursions of gaseous emission levels during transients were not so pronounced as to cause marked changes in overall emissions from the snowmobile engines tested. It was noted, however, that a full-throttle acceleration against load after a prolonged idle sometimes produced a rather noticeable smoke puff lasting from a few seconds to perhaps 30 seconds. The duration and intensity of the puff seemed to vary directly with amount of time spent at idle prior to the acceleration and with oil concentration in the fuel. An example of the appearance of such a smoke puff will be given in a later section of the report.

TABLE 2. ENGINE SPEED AND LOAD CONDITIONS USED FOR EMISSIONS TESTS

	Arctic Cat 440			Polaris 335			Rotax 248			OMC 528 Rotary		
	Condition			Condition			Condition			Condition		
Mode	rpm	Load	Notes	rpm	Load	Notes	rpm	Load	Notes	rpm	Load	Notes
1	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2
2	5500	0	1, 3	4500	0	1, 3	4000	0		3500	0	
3	5500	1/8		4500	1/4	1, 2	4000	1/8		3500	1/8	
4	5500	1/4		4500	1/2	1, 3	4000	1/4	1	3500	1/4	1, 2
5	5500	1/2	1, 3	4500	3/4	1, 2	4000	1/2	1, 2, 3	3500	1/2	1, 2
6	5500	3/4	1	4500	100	1, 3	4000	3/4	1	3500	3/4	
7	5500	7/8	1	2500	1/4	1, 2	4000	7/8		3500	full	
8	5500	full	1, 2, 3	2500	1/8		4000	full	3	2500	1/2*	
9	2500	full	1, 2, 3	2500	0	1, 2, 3	3000	3/4		2500	1/4*	1
10	2500	7/8		5500	0	3	3000	1/2	1, 3	2500	0	1, 2
11	2500	3/4		5500	1/4		3000	1/4	1, 2	6000	0	
12	2500	1/2	1, 3	5500	1/2	1, 3	3000	1/8		6000	1/4	
13	2500	1/4		5500	3/4	1	3000	0	1, 3	6000	1/2	
14	2500	1/8		5500	7/8		6500	0		6000	3/4	1, 2
15	2500	0	1, 2, 3	5500	full	1, 3	6500	1/4		6000	7/8	
16	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2
17	4000	full	1, 2, 3	7000	full	1	6500	1/2	3	6000	full	1, 2
18	4000	7/8		7000	7/8		6500	3/4	1	4000	full	
19	4000	3/4		7000	3/4	1	6500	7/8		4000	7/8	
20	4000	1/2	1, 3	3500	0	1	6500	full	1, 2, 3	4000	3/4	1
21	4000	1/4		3500	1/8		5000	full	1, 2, 3	4000	1/4	1
22	4000	1/8		3500	1/4	1	5000	7/8		4000	1/8	
23	4000	0	1, 2, 3	3500	1/2	1	5000	3/4	1, 2	4000	0	
24	7000	0	1, 3	3500	3/4		5000	1/2	1, 3	5000	0	
25	7000	1/8		3500	full		5000	1/4		5000	1/8	
26	7000	1/4		6500	full	2, 3	5000	0	3	5000	1/4	
27	7000	1/2	1, 3	6500	7/8		2500	0	1, 2, 3	5000	1/2	1
28	7000	3/4	1	6500	3/4	2, 3	2500	1/8		5000	3/4	1, 2
29	7000	7/8	1	6500	1/2		2500	1/4	1	5000	7/8	
30	7000	full	1, 2, 3	6500	0	3	2500	1/2	3	5000	full	1
31	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2, 3	Idle	0	1, 2

Note: All conditions used for gaseous emissions measurements
1. Condition used for light HC and aldehyde measurements
2. Condition used for particulate measurements
3. Condition used for smoke measurements

* These loads were estimated because the engine was not to be run at full load under 3500 rpm

Engine operating data and other data acquired during the tests included intake and exhaust pressures, intake air and exhaust gas temperatures, and spark plug seat and/or other critical engine temperatures, in addition to ambient conditions and other data already discussed. Complete raw data from all the continuous gaseous emissions tests are included in the Appendix; and the data from the aldehyde, light hydrocarbon, particulate, and smoke evaluations will be presented in Section IV of the text. All the data presented in concentrations (in both text and appendix) will be expressed on a "wet" basis, that is, as measured at the exhaust outlet before removal of water vapor from the sample, or as corrected back to those conditions mathematically.

Lubrication of the test engines was a very important consideration, since they were all lubricated by oil mixed with the fuel. The recommended practice of the manufacturers was followed in all cases except one, that being the Rotax, which was run for gaseous emissions measurements at 20:1 gasoline:oil ratio instead of 50:1 as recommended. This measure was followed to ensure reliability, in light of (1) problems with other engines when run oil-lean, (2) a possible time lag in obtaining parts from Canada should something go wrong, and (3) the assumption that oil concentration should have relatively little to do with hydrocarbon concentrations. The Rotax was run at both 20:1 and 50:1 for smoke and particulate evaluations, and the particular oil used was a TCW-qualified Chrysler oil. Bombardier's recommendation read, "we recommend our ski-doo oil at 50/1 ratio--any good snowmobile two cycle oil could be used."

The Arctic Cat 440 was run at 20:1 using Arctic's "Modified Purple Powerlube" oil. The Polaris 335 was initially run at 40:1 but was switched to 20:1 after encountering a piston seizure. Particulate and smoke measurements were made at both 20:1 and 40:1 ratios, and the particular oil used was a TCW-qualified oil marketed by Evinrude. The OMC rotary was run at 50:1 using a special OMC rotary engine oil marketed only for that purpose.

D. Calculations and Unmeasured Emissions

In converting emission measurements to mass rates, the first step usually taken is conversion of concentrations measured "dry" to a "wet" basis. One of the complicating factors in this mathematical process is the presence of water vapor in the intake air; but in the case of the snowmobile engine tests, this problem was effectively eliminated by the intake air cooling system. It is safe to assume that the intake air, cooled to about 20°F, was saturated with water vapor. The saturation value, however, would be so low as to be negligible; and thus the intake air can be assumed as dry air for calculation purposes at the temperatures listed in the Appendix tables for each mode. All the concentration data appearing in this report are on a wet basis, as already mentioned.

To avoid placing air flow measurement devices upstream of the engine air intakes and thereby running the risk of upsetting air flow and engine performance, it was decided to measure fuel flow rates and compute mass emissions using a fuel-based procedure. The following definitions and equations were used to make the concentration-to-mass flow conversion on a mode-by-mode basis:

F	= fuel rate, lb_m/hr	
TC	= total carbon = % CO + % CO_2 + (ppmC x 10^{-4})	
HC(g/hr)	= 0.0454(ppmC) (F/TC)	
CO(g/hr)	= 916.(%CO) (F/TC)	
NO_x(g/hr)	= 0.150(ppmNO_x) (F/TC)	as NO_2 (ppm NO_x by chemiluminescence)
RCHO(g/hr)	= 0.0982(ppm RCHO) (F/TC)	as HCHO
Particulate(g/hr)	= 2.79(Particulate mg/SCF) (F/TC)	

The only major assumption made in forming these equations was that fuel composition approximated $(CH_{1.85})_n$, for which many good precedents exist[5]. Note also that total aliphatic aldehydes (RCHO) are expressed "as HCHO" to fix an assumed molecular weight per carbonyl group. All the NO_x mass rates and brake specific rates in this report, as well as NO and NO_x concentrations, are on a wet basis but not "corrected" to a standard ambient humidity by one of several equations available for the purpose[6, 7]. The reasons that NO_x is not being "corrected" here are that (1) no work has been done to establish an applicable relationship of NO_x to humidity for either the 2-stroke SI engine or the rotary and (2) the standard ambient humidity used in existing equations (75 grains H_2O/lb_m dry air) is far from correct for normal snowmobile operation. It should also be noted that the NO_x mass and brake specific rates are based on NO_x concentrations measured by the chemiluminescent instrument.

Although a number of important exhaust constituents were measured during the snowmobile engine tests, a few measurements of less important emissions were neglected due either to time and financial constraints or the lack of a reliable analysis method. Using these criteria, it was decided to estimate emissions of sulfur oxides (SO_x), evaporative hydrocarbons, and crankcase (blowby) hydrocarbons rather than attempt to measure them.

Beginning with evaporative hydrocarbons and crankcase hydrocarbons, they will both be neglected but for different reasons. In the case of evaporation, it is recognized that winter fuel Rvp's (Reid vapor pressures) are high enough to permit evaporation under some conditions, but it is felt that the generally low temperatures under which snowmobiles are operated and stored will make evaporation negligible. Regarding crankcase losses, the 2-stroke engines use crankcase induction; so they produce no crankcase losses. The rotary engine tested has no oil sump either, nor does it have other design features which would permit unburned fuel-air mixture to escape into the atmosphere; so none of the snowmobile engines tested produce any losses of fuel-air mixture past combustion chamber seals to the atmosphere. Although it has not been possible to check on all the engine models currently being produced, it seems doubtful that any of them produce blowby losses; and the zero-loss situation will be assumed for the purposes of this report.

In the case of SO_x, instrumentation for the measurement of this pollutant in raw exhaust has not been developed to the same extent as that for other common constituents; so it has become more or less accepted practice to calculate sulfur oxide emissions based on fuel sulfur content. In a 4-stroke gasoline engine or a diesel in which substantially all the fuel is burned (perhaps 99 percent or more), the assumption is usually made that all the sulfur in the fuel oxidizes to SO_2. This assumption leads to computation of an SO_2 mass emission rate which is 2.00 times the rate at which sulfur enters the engine in the fuel (2.00 = molecular weight of SO_2/atomic weight of S). For snowmobile engines, however, a fairly significant fraction of the fuel is emitted without being burned at all (from 2 to 4 percent for the Wankel tested to 24 to 35 percent for the 2-stroke engines based on cycle composites) which means that roughly the same fraction of fuel sulfur is being emitted without being oxidized. Emissions of sulfur oxides, then, are computed for snowmobile engines in the same way as for other engines, except that the final result is multiplied by the fraction of fuel burned before being reported as SO_2.

Prior to estimation of emission factors and national impact, emissions will be computed on a cycle composite basis by assuming that each mode listed in Table 2 occupied some fraction of total snowmobile operating time (the fractions can be zero, of course). In terms of definitions and equations:

M_i = individual mode emissions, g/hr
F_i = individual mode fuel consumption, lb_m/hr
hp_i = individual mode power, hp
W_i = individual time-based mode weighting factor
i = mode number (1 to 31)

$$\text{cycle composite g/hr} = \sum_{i=1}^{31} M_i W_i$$

$$\text{cycle composite g/hp-hr} = \frac{\sum_{i=1}^{31} M_i W_i}{\sum_{i=1}^{31} hp_i W_i}$$

If it appeared desirable for some reason, fuel specific emissions could also be computed by the relation:

$$\text{cycle composite g/lb}_m \text{ fuel} = \frac{\sum_{i=1}^{31} M_i W_i}{\sum_{i=1}^{31} F_i W_i}$$

The desirability of performing this calculation might arise if, for example, it were determined that reliable data on total fuel consumption by snowmobiles did exist. The weighting factors to be used in computing cycle composite emissions will be developed in a later report section (V), based on the best data available from manufacturers, snowmobile publications, and the International Snowmobile Industry Association (ISIA).

IV. EMISSION TEST RESULTS

This section includes concentration data on aldehydes, light hydrocarbons, particulate, and smoke; and it also includes mass and brake specific emission rates for HC, CO, NO_x, RCHO (aldehydes), particulate, and SO_x. These rates are presented on a mode-by-mode basis, and cycle composites will be given in a later section of the report. Concentration data for the gaseous emissions measured continuously are presented in the Appendix (all concentrations on a wet basis).

A. Aldehyde and Light Hydrocarbon Concentrations

Aldehydes were generally measured during two or three runs and only at those conditions which were considered most important in each engine's operation. Variation in mode choices also occurred due to inability of some engines to maintain operating temperatures below specified maximum limits for the required sampling period. The number of test modes was restricted because there is a long analysis time involved with each sample, and the importance of aldehyde emissions is not so great as to justify time and efforts which might compromise some other part of the test program. The intended numbers of aldehyde measurements were acquired for all the engines except the OMC rotary, which encountered operating difficulties beyond the contractor's maintenance abilities and had to be removed from the test program prematurely.

Concentrations of formaldehyde (HCHO) and total aliphatic aldehydes (RCHO) are given in Table 3, and the most noticeable features of these data (for 2-strokes) are their relatively high concentrations and their relatively small total variation (range of RCHO from 106 to 531 ppm, or about 5-to-1) as compared with other emissions. Although four data points cannot be considered even strongly indicative, let alone conclusive, it appears that aldehyde concentrations from the rotary engine might be substantially lower than those from the 2-stroke reciprocating engines. The aldehyde concentrations from the snowmobile engines are in the same general range as those measured for other 2-stroke engines (such as motorcycles[8] and small utility engines[9]) under the subject contract. They are generally quite a bit higher, however, than those measured during this project for either 4-stroke gasoline engines[8, 9, 11] or diesel engines[10, 11].

Light hydrocarbons were measured during most of the same modes as aldehydes, and this measurement was made using bag samples of exhaust which could be analyzed by gas chromatograph as time permitted. Depending on sample composition, time required to analyze one bag of

TABLE 3. SUMMARY OF AVERAGE* ALDEHYDE CONCENTRATIONS FROM FOUR SNOWMOBILE ENGINES

Condition		Arctic Cat 440 Data	
rpm	Load	HCHO, ppm	RCHO, ppm
1560	Idle	104	209
2500	0	103	186
2500	1/2	121	221
2500	full	166	246
4000	0	59	158
4000	1/2	148	205
4000	full	239	531
5500	0	60	160
5500	1/2	100	187
7000	0	47	116
7000	1/4	100	160

Condition		Rotax 248 Data	
rpm	Load	HCHO, ppm	RCHO, ppm
1850	Idle	83	106
2500	0	140	208
2500	1/4	80	158
3000	1/4	74	141
3000	1/2	140	186
4000	1/4	70	153
4000	1/2	69	155
4000	3/4	117	175
5000	1/2	141	185
5000	3/4	110	172
5000	full	161	177
6500	3/4	140	181
6500	full	148	165

Condition		Polaris 335 Data	
rpm	Load	HCHO, ppm	RCHO, ppm
1010	Idle	158	189
2500	0	93	197
2500	1/4	94	174
3500	0	160	188
3500	1/4	---	---
3500	1/2	199	245
4500	0	141	266
4500	1/4	156	281
4500	1/2	278	407
4500	3/4	260	400
4500	full	156	328
5500	1/2	142	367
5500	3/4	177	423
5500	full	---	---
7000	3/4	151	261
7000	full	125	283

Condition		OMC 528 Rotary Data(a)	
rpm	Load	HCHO, ppm	RCHO, ppm
2500	0	29	47
2500	1/4(b)	19	47
3500	1/4	14	20
3500	1/2	17	24

* Two runs in most cases

(a) Tests aborted due to engine problems one run only

(b) Estimated

exhaust ranged up to one hour, pointing up the need to keep the total number of samples to a minimum. Light hydrocarbons are of interest primarily because concentrations of combustion products (hydrocarbons not normally present in the fuel) are indicative of processes occurring within the engine. Table 4 gives the data obtained on snowmobile engines, generally showing a rather complex mixture of combustion products. The propane concentrations were uniformly low, because there is little propane in the fuel and because it does not occur often as a combustion product. Butane concentrations were more variable and were probably quite proportional to total hydrocarbon concentrations. Butane evaporates rapidly, even at room temperatures, so some of the butane variation is possibly due to evaporation during the hours over which the tests were conducted.

On the basis of average concentrations in ppm C for the 2-stroke engines, the alkenes (C_2H_4 and C_3H_6) and unburned fuel (C_3H_8 and C_4H_{10}) were roughly equal; and these two categories made up over 80 percent of the light hydrocarbons. The remainder was mostly alkanes (CH_4 and C_2H_6) with a small fraction of acetylene (C_2H_2). The few samples taken on the OMC rotary indicate a very small fraction of unburned fuel and roughly 50 percent alkenes, 30 percent alkanes, and 20 percent acetylene. The total ppm C in light hydrocarbons for the 2-strokes averaged about 3300, with about 2000 ppm C of this amount in combustion products. The light hydrocarbons totalled an average of about 2300 ppm C for the OMC rotary, virtually all of which was combustion products.

B. Major Gaseous Emissions Results

As already mentioned in the introduction to Section IV, data on concentrations of major gaseous emissions (those measured by continuous techniques) are given in the Appendix. The data given here in the text are in mass rates and brake specific rates and could easily be computed on a fuel specific basis if it were shown to be desirable by available statistics.

Average mass and specific emissions are given in Tables 5 through 9 on a mode-by-mode basis. Tables 5, 7, 8, and 9 present data for regular tests on the Arctic, Polaris, Rotax, and OMC engines, respectively. Table 6 shows information gathered on the Arctic engine using a richer high-speed jet setting, a modification recommended for field usage where operating temperatures are difficult to hold down. These tables contain a great many individual items of information which are difficult to interpret, so the data will also be presented in other ways. These presentations will include calculation of composite emissions in a later report section, as well as graphical presentation in this section as functions of engine load with engine speed as parameter.

TABLE 4. CONCENTRATIONS OF LIGHT HYDROCARBONS IN THE EXHAUST OF FOUR SNOWMOBILE ENGINES

Arctic Cat 440

Condition		Concentrations in ppm						
rpm	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
1560	Idle	1610	148	971	16	1300	974	877
2500	0	98	32	149	0	0	419	0
2500	1/2	65	32	143	0	0	343	0
2500	full	342	0	0	0	0	0	0
4000	0	114	35	168	0	11	706	0
4000	1/2	189	89	341	0	0	0	438
4000	full	258	82	400	0	0	0	444
5500	0	204	18	116	0	137	25	400
5500	1/2	159	19	176	0	32	257	0
5500	full	225	64	302	0	0	407	0
7000	0	49	7	85	0	0	0	0
7000	1/4	209	33	210	0	53	51	448
7000	1/2	246	51	222	0	0	432	0
7000	full	367	61	737	0	0	910	0

Polaris 335

Condition		Concentrations in ppm						
rpm	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
1010	Idle	384	176	301	0	55	26	43
2500	0	621	44	268	0	722	0	513
2500	1/4	246	29	183	0	101	281	393
3500	1/4	456	258	275	17	137	213	1900
3500	1/2	235	131	428	0	23	340	0
4500	0	439	179	779	0	225	549	592
4500	1/4	611	230	895	12	151	0	654
4500	1/2	326	123	573	0	27	539	202
4500	3/4	325	93	537	4	63	526	310
5500	1/2	406	34	191	4	193	415	206
5500	3/4	611	154	681	0	169	488	339
5500	full	366	51	298	0	146	408	206
7000	full	268	55	223	7	231	75	61

(continued)

TABLE 4 (Cont'd). CONCENTRATIONS OF LIGHT HYDROCARBONS IN THE EXHAUST OF FOUR SNOWMOBILE ENGINES

Rotax 248

Condition		Concentrations in ppm						
rpm	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
1850	Idle	113	54	241	31	77	104	533
2500	0	106	53	232	37	69	110	546
2500	1/4	63	39	194	31	43	95	487
3000	1/4	86	59	250	29	56	80	460
3000	1/2	111	56	280	24	67	80	444
4000	1/4	119	84	351	29	64	74	494
4000	1/2	219	41	223	30	81	74	410
4000	3/4	127	78	359	27	39	70	498
5000	1/2	191	145	528	31	54	65	574
5000	3/4	201	151	556	31	52	66	575
5000	full	153	128	504	39	39	89	607
6500	3/4	398	239	811	26	118	57	753
6500	full	351	224	802	28	102	59	750

OMC 528 Rotary[a]

Condition		Concentrations in ppm						
rpm	Load	CH_4	C_2H_6	C_2H_4	C_3H_8	C_2H_2	C_3H_6	C_4H_{10}
2500	0	1280	104	680	0	946	288	15
2500	1/4[b]	563	39	301	3	220	175	3
3500	1/4	552	48	386	0	208	141	17
3500	1/2	352	41	271	0	133	106	0

(a) Tests aborted due to engine problems one run only
(b) Estimated

TABLE 5. AVERAGE FUEL RATES, MASS EMISSIONS, AND BRAKE SPECIFIC EMISSIONS FOR AN ARCTIC CAT 440 SNOWMOBILE ENGINE

Condition		Fuel,	Mass Emissions in g/hr						Specific Emissions in g/hp-hr					
rpm	Load	lb_m/hr	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]
1560	Idle	1.56	347.	373.	0.18	1.8	10.4	0.16	-------	------	-----	----	----	----
2500	0	1.77	243.	388.	0.27	1.9	19.3	0.24	-------	------	-----	----	----	----
2500	1/8	1.95	262.	230.	0.35	-----	------	0.27	276.	242.	0.37	----	----	0.28
2500	1/4	2.27	278.	256.	0.70	-----	------	0.32	146.	135.	0.37	----	----	0.17
2500	1/2	3.32	478.	21.3	3.68	5.7	------	0.44	128.	5.73	0.99	1.5	----	0.12
2500	3/4	4.71	642.	210.	12.4	-----	------	0.64	111.	36.3	2.14	----	----	0.11
2500	7/8	6.96	1090.	1990.	3.51	-----	------	0.89	166.	304.	0.55	----	----	0.14
2500	full	6.34	903.	60.7	80.1	10.	66.9	0.85	122.	8.21	10.8	1.4	9.05	0.11
4000	0	2.32	419.	93.0	0.90	2.6	15.7	0.27	-------	------	-----	----	----	----
4000	1/8	2.70	351.	44.9	1.46	-----	------	0.38	183.	23.4	0.76	----	----	0.20
4000	1/4	3.07	285.	38.7	1.84	-----	------	0.48	87.9	11.9	0.57	----	----	0.15
4000	1/2	5.65	477.	510.	7.90	7.6	------	0.90	63.3	67.7	1.05	1.0	----	0.12
4000	3/4	8.71	874.	2340.	8.78	-----	------	1.32	79.4	213.	0.80	----	----	0.12
4000	7/8	9.66	1070.	2000.	25.8	-----	------	1.42	81.8	153.	1.97	----	----	0.11
4000	full	10.3	1230.	1120.	92.7	35.	65.2	1.48	86.3	78.2	6.48	2.5	4.56	0.10
5500	0	3.06	131.	36.6	1.27	3.8	------	0.54	-------	------	-----	----	----	----
5500	1/8	3.34	150.	22.4	1.56	-----	------	0.59	41.8	6.24	0.43	----	----	0.16
5500	1/4	4.84	259.	36.8	6.84	-----	------	0.83	38.5	5.47	1.01	----	----	0.12
5500	1/2	8.40	1210.	3460.	18.1	9.6	------	1.12	83.2	239.	1.25	0.66	----	0.08
5500	3/4	15.7	1610.	3360.	55.9	-----	------	2.37	75.2	157.	2.61	----	----	0.11
5500	7/8	17.3	2090.	4820.	53.6	-----	------	2.48	79.5	183.	2.03	----	----	0.09
5500	full	20.7	2570.	3290.	203.	-----	110.	2.93	91.5	117.	7.22	----	3.93	0.10
7000	0	3.56	169.	53.6	1.34	3.0	------	0.62	-------	------	-----	----	----	----
7000	1/8	5.73	351.	154.	9.50	-----	------	0.97	86.2	37.8	2.33	----	----	0.24
7000	1/4	8.43	718.	1760.	8.98	8.4	------	1.34	86.3	211.	1.08	1.0	----	0.16
7000	1/2	15.3	1650.	4850.	14.2	-----	------	2.27	99.3	292.	0.86	----	----	0.14
7000	3/4	20.0	2170.	4220.	51.1	-----	------	2.97	88.6	172.	2.09	----	----	0.12
7000	7/8	26.0	3300.	7140.	40.7	-----	------	3.65	119.	257.	1.46	----	----	0.13
7000	full	23.3	2730.	3430.	154.	-----	147.	3.37	87.3	110.	4.92	----	4.69	0.11

(a) These particulate data are for a 20:1 gasoline:oil ratio
(b) Calculated

TABLE 6. AVERAGE FUEL RATES, MASS EMISSIONS, AND BRAKE SPECIFIC EMISSIONS FOR AN ARCTIC CAT 440 SNOWMOBILE ENGINE WITH RICH HIGH-SPEED JET SETTING

Condition		Fuel,	Mass Emissions in g/hr						Specific Emissions in g/hp-hr					
rpm	Load	lb_m/hr	HC	CO	NO_x	RCHO	Part.	SO_x[(a)]	HC	CO	NO_x	RCHO	Part.	SO_x[(a)]
1580	Idle	1.51	323.	336.	0.21	-----	------	0.16	-------	------	-----	----	----	----
2500	0	1.70	288.	293.	0.27	-----	------	0.21	-------	------	-----	----	----	----
2500	1/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
2500	1/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
2500	1/2	3.82	485.	23.1	4.15	-----	------	0.54	126.	6.01	1.08	----	----	0.14
2500	3/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
2500	7/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
2500	full	7.50	1190.	1370.	14.4	-----	------	0.95	159.	182.	1.91	----	----	0.13
4000	0	2.12	373.	54.3	1.54	-----	------	0.25	-------	------	-----	----	----	----
4000	1/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
4000	1/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
4000	1/2	6.61	546.	1330.	7.42	-----	------	1.05	71.3	174.	0.97	----	----	0.14
4000	3/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
4000	7/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
4000	full	13.5	1710.	2510.	38.8	-----	------	1.90	106.	156.	2.41	----	----	0.12
5500	0	3.01	124.	28.1	1.13	-----	------	0.54	-------	------	-----	----	----	----
5500	1/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
5500	1/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
5500	1/2	12.6	1150.	4330.	11.7	-----	------	1.96	79.7	300.	0.81	----	----	0.14
5500	3/4	18.2	2040.	6160.	22.8	-----	------	2.67	94.6	286.	1.06	----	----	0.12
5500	7/8	22.1	2760.	7490.	27.0	-----	------	3.12	109.	295.	1.06	----	----	0.12
5500	full	23.8	2980.	5310.	77.9	-----	------	3.36	107.	190.	2.79	----	----	0.12
7000	0	3.52	180.	25.8	1.78	-----	------	0.61	-------	------	-----	----	----	----
7000	1/8	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
7000	1/4	-----	------	------	------	-----	------	-----	-------	------	-----	----	----	----
7000	1/2	15.9	1680.	5180.	12.1	-----	------	2.38	1/8.	334.	0.78	----	----	0.15
7000	3/4	21.8	2610.	6290.	26.6	-----	------	3.13	109.	262.	1.11	----	----	0.13
7000	7/8	27.7	3860.	9840.	17.9	-----	------	3.74	142.	363.	0.66	----	----	0.14
7000	full	25.7	3440.	5900.	78.7	-----	------	3.53	114.	196.	2.61	----	----	0.12

(a) Calculated

TABLE 7. AVERAGE FUEL RATES, MASS EMISSIONS, AND BRAKE SPECIFIC EMISSIONS FOR A POLARIS 335 SNOWMOBILE ENGINE

Condition		Fuel,	Mass Emissions in g/hr						Specific Emissions in g/hp-hr					
rpm	Load	lb_m/hr	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]
1010	Idle	1.11	237.	216.	0.16	1.2	3.48	0.11	-------	------	-----	----	----	----
2500	0	2.00	436.	483.	0.32	2.1	6.20	0.20	-------	------	-----	----	----	----
2500	1/8	2.29	401.	618.	0.44	2.7	------	0.27	494.	761.	0.54	1.7	----	0.34
2500	1/4	2.45	348.	541.	2.57	-----	8.33	0.33	222.	344.	1.64	----	5.31	0.21
3500	0	2.67	546.	650.	0.58	2.9	------	0.29	-------	------	-----	----	----	----
3500	1/8	3.10	535.	673.	0.75	-----	------	0.37	461.	580.	0.64	----	----	0.32
3500	1/4	3.57	464.	672.	1.59	-----	------	0.50	191.	277.	0.65	----	----	0.20
3500	1/2	4.65	480.	559.	5.25	8.3	------	0.70	90.9	106.	0.99	1.6	----	0.13
3500	3/4	6.25	751.	908.	16.4	-----	------	0.90	96.2	116.	2.10	----	----	0.11
3500	full	13.8	2440.	4580.	27.9	-----	------	1.64	214.	402.	2.45	----	----	0.14
4500	0	3.09	507.	604.	0.82	5.4	------	0.38	-------	------	-----	----	----	----
4500	1/4	4.73	366.	609.	4.29	9.6	8.83	0.77	82.2	137.	0.96	2.2	1.98	0.17
4500	1/2	7.34	657.	1500.	12.3	20.	------	1.15	69.7	159.	1.30	2.2	----	0.12
4500	3/4	11.5	1410.	2740.	33.5	29.	19.3	1.64	98.2	190.	2.33	2.0	1.34	0.11
4500	full	16.7	2820.	5030.	25.0	30.	------	2.04	158.	283.	1.40	1.7	----	0.11
5500	0	3.84	567.	844.	4.86	-----	------	0.51	-------	------	-----	----	----	----
5500	1/4	7.06	484.	1340.	7.92	-----	------	1.17	86.4	239.	1.41	----	----	0.21
5500	1/2	10.3	879.	2430.	16.9	26.	------	1.63	75.1	208.	1.44	2.3	----	0.14
5500	3/4	13.7	1730.	3020.	47.2	40.	------	1.93	102.	177.	2.78	2.4	----	0.11
5500	7/8	17.6	2750.	3600.	70.9	-----	------	2.25	139.	182.	3.58	----	----	0.11
5500	full	21.6	3630.	6730.	37.8	-----	------	2.65	166.	309.	1.73	----	----	0.12
6500	0	3.79	308.	1080.	4.28	-----	------	0.61	-------	------	-----	----	----	----
6500	1/2	11.5	996.	2640.	16.6	-----	------	1.81	77.2	205.	1.29	----	----	0.14
6500	3/4	15.7	1670.	4150.	36.8	-----	27.7	2.34	90.1	224.	1.99	----	1.50	0.13
6500	7/8	16.8	1900.	3060.	83.2	-----	------	2.46	85.8	138.	3.75	----	----	0.11
6500	full	22.2	3200.	6050.	47.6	-----	68.3	2.95	127.	240.	1.89	----	2.71	0.12
7000	3/4	15.9	1740.	3690.	32.4	28.	------	2.35	89.5	190.	1.67	1.4	----	0.12
7000	7/8	19.6	2440.	4250.	69.9	-----	------	2.77	100.	175.	2.88	----	----	0.11
7000	full	23.9	3160.	7150.	43.8	39.	------	3.30	120.	271.	1.66	1.5	----	0.13

(a) These particulate values are for a 40:1 gasoline:oil ratio
(b) Calculated

TABLE 8. AVERAGE FUEL RATES, MASS EMISSIONS, AND BRAKE SPECIFIC EMISSIONS FOR A ROTAX 248 SNOWMOBILE ENGINE

Condition		Fuel,	Mass Emissions in g/hr						Specific Emissions in g/hp-hr					
rpm	Load	lb_m/hr	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]
1850	Idle	0.98	223.	25.4	0.14	0.77	0.96	0.095	-------	------	-----	----	----	----
2500	0	1.13	253.	21.2	0.19	1.8	1.25	0.11	-------	------	-----	----	----	----
2500	1/8	1.45	299.	33.1	0.24	-----	------	0.15	906.	100.	0.73	----	----	0.47
2500	1/4	1.61	309.	32.7	0.30	1.9	------	0.18	507.	53.6	0.49	3.2	----	0.30
2500	1/2	1.86	305.	30.5	0.56	-----	------	0.23	218.	21.8	0.40	----	----	0.17
3000	0	1.57	327.	52.0	0.25	-----	------	0.17	-------	------	-----	----	----	----
3000	1/8	1.72	334.	48.5	0.32	-----	------	0.19	1110.	162.	1.07	----	----	0.64
3000	1/4	1.87	349.	52.5	0.47	2.0	3.97	0.21	465.	70.0	0.63	2.6	5.30	0.29
3000	1/2	2.67	467.	444.	1.20	3.1	------	0.32	265.	252.	0.68	1.8	----	0.18
3000	3/4	3.13	555.	152.	3.08	-----	------	0.37	271.	74.1	1.50	----	----	0.18
4000	0	2.13	430.	74.8	0.33	-----	------	0.23	-------	------	-----	----	----	----
4000	1/8	2.71	456.	217.	0.70	-----	------	0.33	490.	233.	0.76	----	----	0.36
4000	1/4	2.89	446.	155.	1.20	3.2	------	0.37	284.	98.7	0.76	2.0	----	0.24
4000	1/2	4.39	725.	487.	2.24	4.9	13.2	0.54	214.	144.	0.66	1.4	3.89	0.16
4000	3/4	5.10	862.	232.	9.52	6.6	------	0.62	158.	42.6	1.75	1.2	----	0.11
4000	7/8	6.00	1070.	263.	18.5	-----	------	0.71	166.	40.7	2.86	----	----	0.11
4000	full	7.30	1400.	145.	39.6	-----	------	0.82	191.	19.8	5.40	----	----	0.11
5000	0	2.48	434.	94.4	0.86	-----	------	0.30	-------	------	-----	----	----	----
5000	1/4	4.10	574.	390.	2.85	-----	------	0.55	204.	138.	1.01	----	----	0.20
5000	1/2	5.31	797.	86.2	8.94	7.8	------	0.69	145.	15.7	1.63	1.4	----	0.13
5000	3/4	7.07	1100.	299.	22.2	8.9	25.2	0.91	140.	38.1	2.83	1.1	3.22	0.12
5000	7/8	8.28	1380.	368.	39.0	-----	------	1.02	146.	38.9	4.12	----	----	0.11
5000	full	9.56	1760.	288.	52.4	12.	28.9	1.11	166.	27.2	4.94	1.2	2.73	0.10
6500	0	2.17	145.	40.8	1.18	-----	------	0.36	-------	------	-----	----	----	----
6500	1/4	5.52	741.	44.3	6.62	-----	------	0.76	168.	100.	1.50	----	----	0.17
6500	1/2	9.29	1360.	263.	21.3	-----	------	1.23	157.	30.3	2.45	----	----	0.14
6500	3/4	12.0	1830.	452.	56.9	16.	------	1.55	143.	35.3	4.45	1.2	----	0.12
6500	7/8	12.7	2050.	556.	78.3	-----	------	1.60	143.	38.6	5.44	----	----	0.11
6500	full	13.2	2200.	333.	92.2	17.	30.2	1.63	135.	20.6	5.69	1.0	1.86	0.10

(a) These particulate values are for a 50:1 gasoline:oil ratio
(b) Calculated

TABLE 9. AVERAGE FUEL RATES, MASS EMISSIONS, AND BRAKE SPECIFIC EMISSIONS FOR AN OMC 528 ROTARY SNOWMOBILE ENGINE

Condition		Fuel,	Mass Emissions in g/hr						Specific Emissions in g/hp-hr					
rpm	Load	lb_m/hr	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]	HC	CO	NO_x	RCHO	Part.[a]	SO_x[b]
1370	Idle	2.75	302.	974.	0.48	-----	7.22	0.41	-------	------	-----	----	----	----
2500	0	4.07	232.	1700.	1.15	1.1	4.01	0.69	-------	------	-----	----	----	----
2500	1/4[c]	5.18	108.	1840.	2.87	1.5	------	0.96	28.6	487.	0.76	0.41	----	0.26
2500	1/2[c]	6.96	131.	2360.	31.9	-----	------	1.30	17.2	312.	4.21	----	----	0.17
3500	0	5.33	146.	1940.	2.51	-----	------	0.98	-------	------	-----	----	----	----
3500	1/8	6.45	157.	2240.	3.23	-----	------	1.19	53.2	758.	1.09	----	----	0.40
3500	1/4	7.38	127.	2190.	8.22	0.93	8.71	1.38	21.3	369.	1.38	0.16	1.46	0.23
3500	1/2	10.2	151.	3060.	29.9	1.6	19.5	1.92	12.7	257.	2.51	0.13	1.64	0.16
3500	3/4	13.2	210.	4510.	51.1	-----	------	2.48	11.7	252.	2.85	----	----	0.14
3500	full	16.7	287.	5820.	83.8	-----	------	3.13	12.1	247.	3.55	----	----	0.13
4000	0	5.76	97.9	1980.	3.92	-----	------	1.08	-------	------	-----	----	----	----
4000	1/8	6.60	96.7	1850.	4.94	-----	------	1.25	28.5	547.	1.46	----	----	0.37
4000	1/4	7.43	97.4	1360.	16.7	-----	------	1.41	13.6	190.	2.33	----	----	0.20
4000	3/4	15.5	246.	4710.	58.9	-----	------	2.92	11.8	226.	2.83	----	----	0.14
4000	7/8	17.6	303.	57[illegible].	[illegible]2.2	-----	------	3.30	12.3	235.	2.52	----	----	0.13
4000	full	21.1	437.	8650.	40.6	-----	------	3.93	15.7	311.	1.46	----	----	0.14
5000	0	7.54	50.6	947.	11.4	-----	------	1.45	-------	------	-----	----	----	----
5000	1/8	9.84	87.9	1920.	21.4	-----	------	1.88	21.5	472.	5.24	----	----	0.46
5000	1/4	10.9	98.9	2140.	32.7	-----	------	2.08	12.3	266.	4.06	----	----	0.26
5000	1/2	14.1	153.	3450.	50.3	-----	------	2.68	9.56	216.	3.14	----	----	0.17
5000	3/4	18.9	237.	6070.	58.6	-----	24.5	3.58	10.0	257.	2.48	----	1.04	0.15
5000	7/8	22.8	313.	7870.	64.9	-----	------	4.31	11.3	284.	2.34	----	----	0.16
5000	full	25.1	356.	9440.	64.8	-----	------	4.74	10.9	291.	1.99	----	----	0.15
6000	0	9.89	51.4	1250.	17.0	-----	------	1.91	-------	------	-----	----	----	----
6000	1/4	14.6	96.8	3210.	31.3	-----	------	2.81	10.2	338.	3.30	----	----	0.30
6000	1/2	18.5	183.	4870.	55.0	-----	------	3.53	9.68	258.	2.91	----	----	0.19
6000	3/4	23.0	265.	7980.	58.2	-----	29.3	4.37	9.40	283.	2.06	----	1.04	0.16
6000	7/8	25.8	207.	9220.	66.2	-----	------	4.94	6.45	287.	2.06	----	-----	0.15
6000	full	27.7	384.	9190.	55.7	-----	32.4	5.24	11.5	275.	1.67	----	0.97	0.16

(a) These particulate values are for a 50:1 gasoline:oil ratio
(b) Calculated
(c) Estimated - engine could not be run at full load and 2500 rpm to calculate partial loads

The graphs are given as Figures 13 through 16 and include emissions of total hydrocarbons, CO, NO_x, and aldehydes (RCHO). These plots have been made on semi-logarithmic graph paper to permit legible inclusion of mass emissions data which span wide ranges, almost three decades in some cases. Note also that all four graphs on any one page do not necessarily have the same ordinate, due to the rather large variations from engine to engine for some emissions. The major purpose of Figures 13 through 16 is to show trends in mass emissions with engine load and speed, and any ambiguity in the assignment of parameters can be resolved by referring to Tables 5, 7, 8, and 9. These tables are likewise to be consulted when specific mode values are needed, because the accuracy of the plots is low compared to tabular values. Note that on semi-log paper, the ordinate of a curve calculated from constant concentration values would increase with increasing load but that it would decrease in slope with increasing load (it would be concave downward). Neglecting the zero-load point, the 6500 rpm curve for the Rotax in Figure 13 (HC mass emissions) is a reasonably good approximation of a constant-concentration curve.

Referring to Figure 13 again, HC emissions ranged from about 130 g/hr to about 3600 g/hr for the 2-stroke engines. The range for the OMC rotary was from about 50 g/hr to about 440 g/hr. Effects of speed on mass emissions of HC were relatively uniform for the 2-stroke engines, with higher speeds producing more HC under most conditions. Emissions of HC from the OMC rotary, however, were only slightly dependent on speed. All the engines exhibited HC emissions quite strongly dependent on load (or throttle opening). Hydrocarbon emissions from the Rotax were quite high, considering its small size, probably as a result of a high delivery ratio.

Figure 14 shows CO emissions, and the scatter in evidence for the Arctic 440 and the Rotax 248 is probably due primarily to changes in fuel/air ratio. As has been shown in other studies[12, 13, 14], CO production is very sensitive to fuel/air ratio. In addition, not all the test modes were used during any one run on the Arctic 440 (high load conditions were run last, and only for short times, to prevent engine overheating); so some day-to-day variations may be in evidence. Of particular interest, also, are the consistently low (although not entirely smooth) CO emissions from the Rotax 248 (20 to 560 g/hr) and the consistently high CO emissions from the OMC 528 rotary (950 to 9440 g/hr). The low CO values for the Rotax as compared to the other 2-strokes probably result from a high delivery ratio and consequent good scavenging.

Emissions of NO_x for the four engines are shown in Figure 15, and here the speed and load effects are quite pronounced. These NO_x values are generally very low, with few data points exceeding 100 g/hr. Although relation of NO_x emissions to the independent variable and parameter differs from engine to engine, mass emissions over a composite

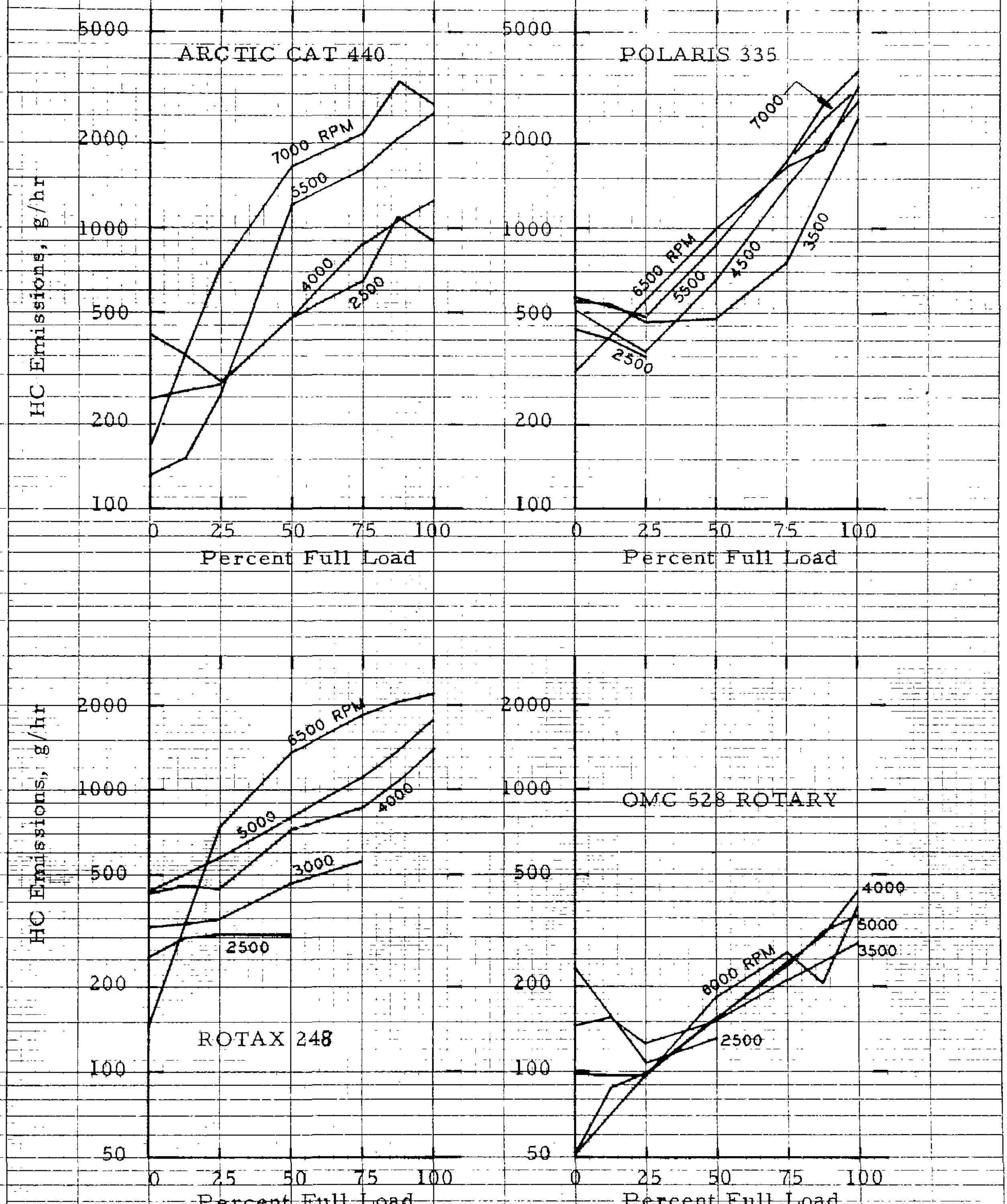

FIGURE 13. HYDROCARBON EMISSIONS FROM FOUR SNOWMOBILE ENGINES AS FUNCTIONS OF LOAD, WITH ENGINE SPEED AS PARAMETER - DATA FROM TABLES 5, 7, 8, AND 9

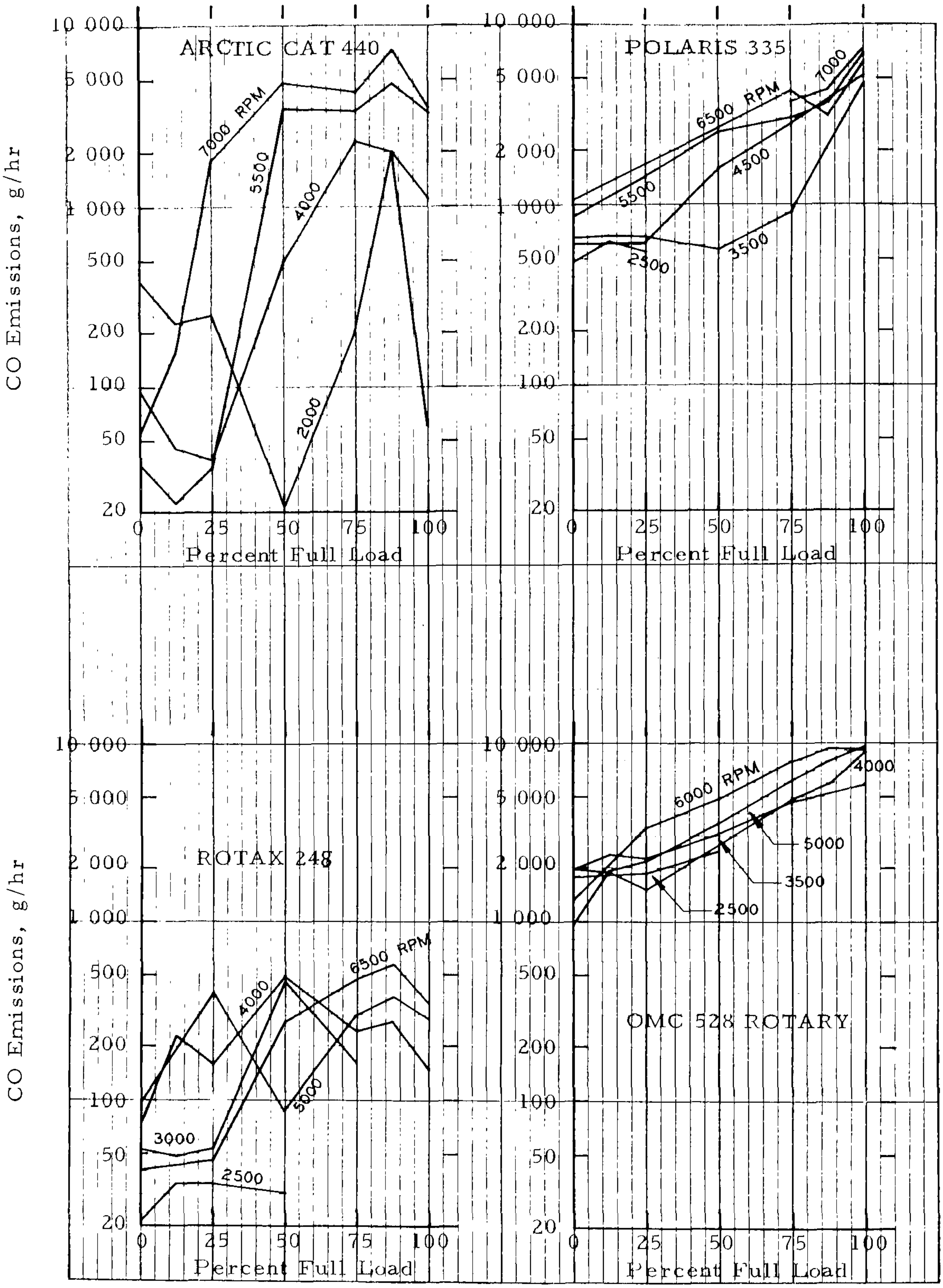

FIGURE 14. CARBON MONOXIDE EMISSIONS FROM FOUR SNOWMOBILE ENGINES AS FUNCTIONS OF LOAD, WITH ENGINE SPEED AS PARAMETER DATA FROM TABLES 5, 7, 8, AND 9

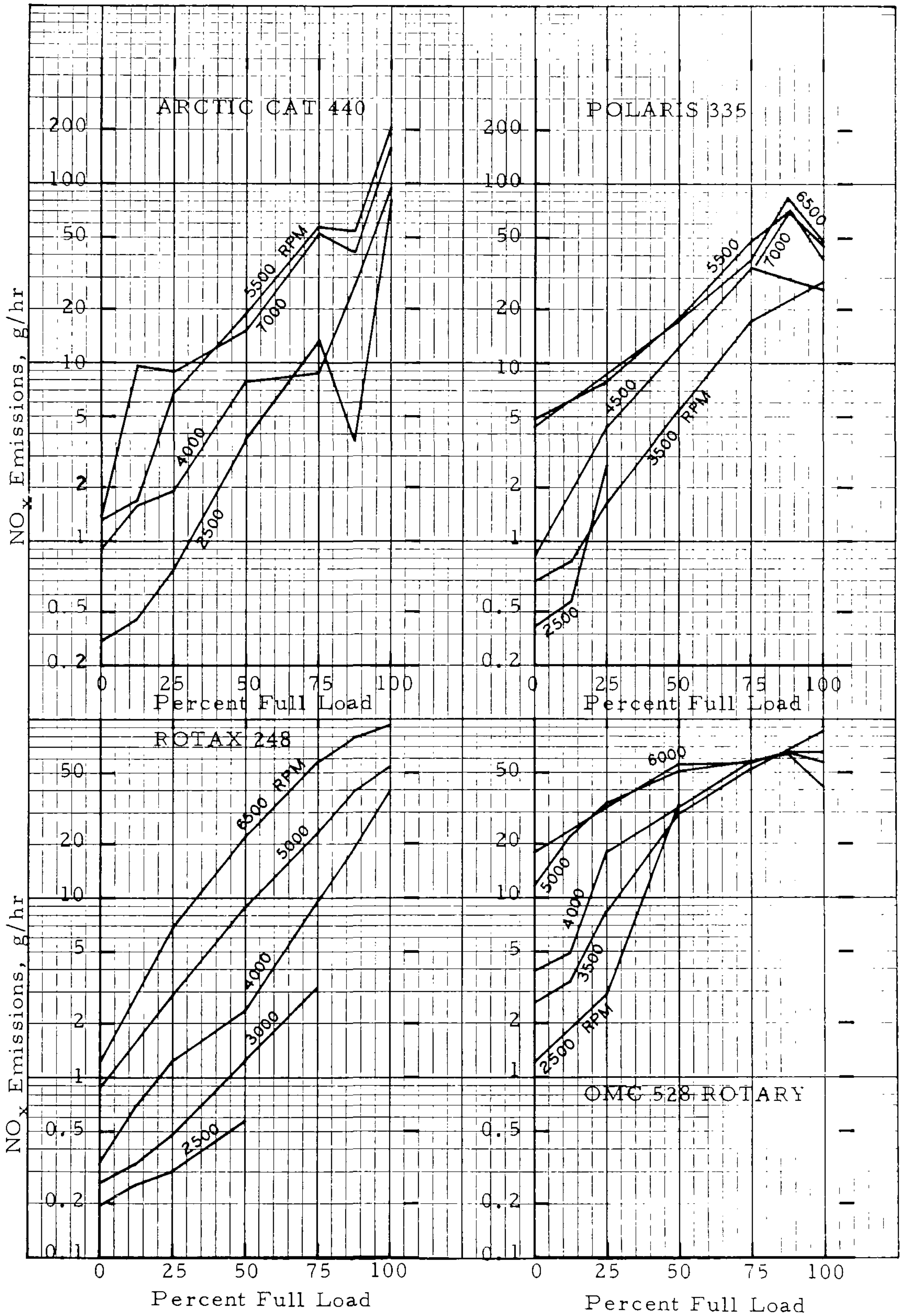

FIGURE 15. OXIDES OF NITROGEN EMISSIONS FROM FOUR SNOWMOBILE ENGINES AS FUNCTIONS OF LOAD, WITH ENGINE SPEED AS PARAMETER - DATA FROM TABLES 5, 7, 8, AND 9

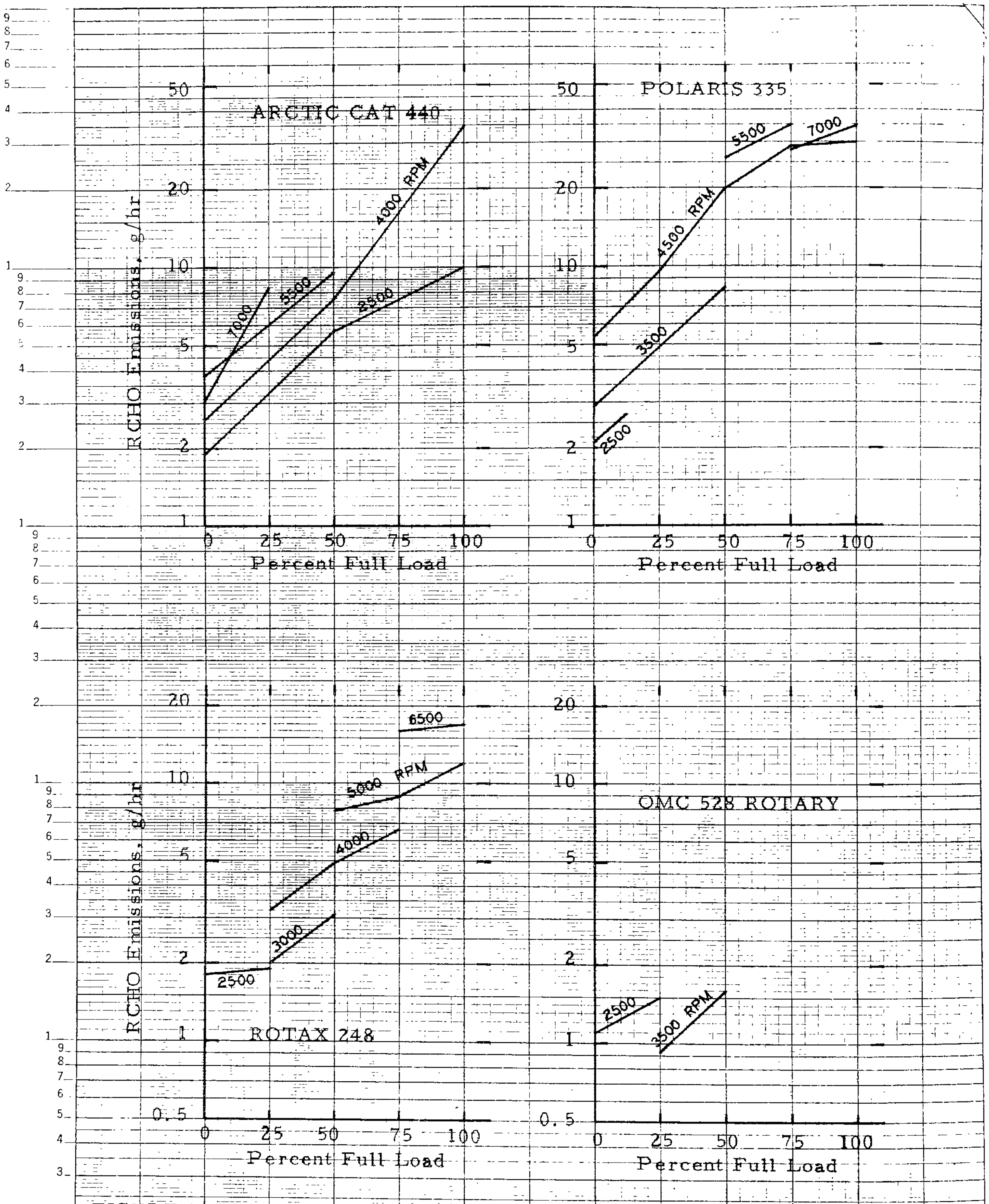

FIGURE 16. TOTAL ALIPHATIC ALDEHYDE (RCHO) EMISSIONS FROM FOUR SNOWMOBILE ENGINES AS FUNCTIONS OF LOAD, WITH ENGINE SPEED AS PARAMETER - DATA FROM TABLES 5, 7, 8, and 9

cycle of realistic operation will probably not vary over a wide range from one engine to another. Although NO_x mass emissions from the OMC rotary peaked out at levels equal to or below peak levels from the 2-strokes, NO_x from the rotary was generally higher at mid-load and low load conditions.

The curves showing mass emissions of total aliphatic aldehydes in Figure 16 are somewhat sketchy compared to those already analyzed. The reason for the lesser number of data points for aldehydes is simply that wet chemistry analysis is time-consuming, and the importance of the aldehyde measurements did not justify a larger effort. Aldehydes show quite a strong dependence on speed and load for the 2-stroke engines, but an insufficient number of points were acquired on the OMC rotary for the drawing of such conclusions. It should be noted, however, that the few points acquired for the rotary engine were somewhat below comparable data for the 2-strokes.

C. Particulate and Smoke Results

Particulate measurements were taken on the exhausts of the snowmobile engines using the experimental sampler described in Section III. B. and shown in Figure 11. The results of these measurements were first obtained on a concentration basis, and they are presented in concentration terms in Table 10 to document variability. Table 10 shows that reasonable repeatability was achieved for most conditions and that differences from one condition to another, one engine to another, and one fuel mixture to another were the more important types of variation. For all conditions except one (Polaris 335, 6500 rpm full load), higher oil concentrations in a given engine produced higher particulate concentrations.

Using data on mass emissions from Tables 5, 7, 8, and 9, Figure 17 was constructed to provide a better feel for particulate variation with speed, load, and engine. The overall trend is an increase in particulates emitted with increasing speed and load, which is not a surprising result. The data plotted in Figure 17 are for the gasoline:oil ratios recommended by the respective engine manufacturers for the 1972-1973 models, although other data are available (Table 10) to show the influence of oil concentration on particulate emissions. The particulate data obtained at oil concentrations other than those recommended by the manufacturers are shown in Figure 17 on the graphs for the Polaris and Rotax engines.

Smoke measurements were obtained on the three 2-stroke snowmobile engines using the PHS smokemeter shown earlier in Figure 12. No smoke measurements were acquired on the OMC rotary engine. It should be noted that the PHS smokemeter was used as a research tool only and not because it is recommended for use with white smoke. While it is felt that the meter gives accurate results as to the opacity of white

TABLE 10. PARTICULATE CONCENTRATION DATA ON FOUR SNOWMOBILE ENGINES

Condition		Particulate Conc., mg/SCF			
rpm	Load	Run 1	Run 2	Run 3	Avg.
		Arctic 440, 20:1 Fuel Mix			
1560	Idle	39.3	40.9	49.8	43.3
2500	0	63.8	66.2	69.9	66.6
2500	full	43.1	70.7	55.4	56.4
4000	0	28.2	40.6	30.8	33.2
4000	full	34.7	33.1	35.3	34.4
5500	full	32.0	22.2	27.6	27.3
7000	full	35.2	29.2	-----	32.2
		Polaris 335, 40:1 Fuel Mix			
1010	Idle	11.7	26.7	-----	19.2
2500	0	21.3	19.2	-----	20.2
2500	1/4	17.8	20.0	-----	18.9
4500	1/4	10.0	8.30	-----	9.15
4500	3/4	10.3	8.28	-----	9.29
6500	3/4	9.87	9.92	-----	9.90
6500	full	16.5	18.9	-----	17.7
		Rotax 248, 50:1 Fuel Mix			
1850	Idle	3.67	5.63	-----	4.65
2500	0	4.42	5.94	-----	5.18
3000	1/4	8.88	11.4	-----	10.1
4000	1/2	14.3	15.0	-----	14.6
5000	3/4	16.0	18.4	-----	17.2
5000	full	12.9	16.4	-----	14.6
6500	full	9.76	11.4	-----	10.6

Condition		Particulate Conc., mg/SCF			
rpm	Load	Run 1	Run 2	Run 3	Avg.
		Polaris 335, 20:1 Fuel Mix			
1010	Idle	26.4	36.1	-----	31.2
2500	0	59.3	41.0	-----	50.2
2500	1/4	26.3	22.7	-----	24.5
4500	1/4	9.96	8.49	-----	9.22
4500	3/4	12.5	12.3	-----	12.4
6500	3/4	10.6	10.4	-----	10.5
6500	full	13.5	15.6	-----	14.6
		Rotax 248, 20:1 Fuel Mix			
1850	Idle	43.4	36.6	-----	40.0
2500	0	34.4	33.8	-----	34.1
3000	1/4	30.8	34.4	-----	32.6
4000	1/2	37.6	34.3	-----	36.0
5000	3/4	26.7	23.7	-----	25.2
5000	full	28.1	27.1	-----	27.6
6500	full	21.0	19.8	-----	20.4
		OMC 528 Rotary, 50:1 Fuel Mix			
1370	Idle	14.3	12.8	14.3	13.8
2500	0	6.61	3.62	7.75	5.99
3500	1/4	6.58	6.71	5.58	6.29
3500	1/2	10.6	9.67	10.1	10.1
5000	3/4	8.48	5.93	7.56	7.32
6000	3/4	8.62	7.34	5.98	7.31
6000	full	7.51	7.27	6.00	6.93

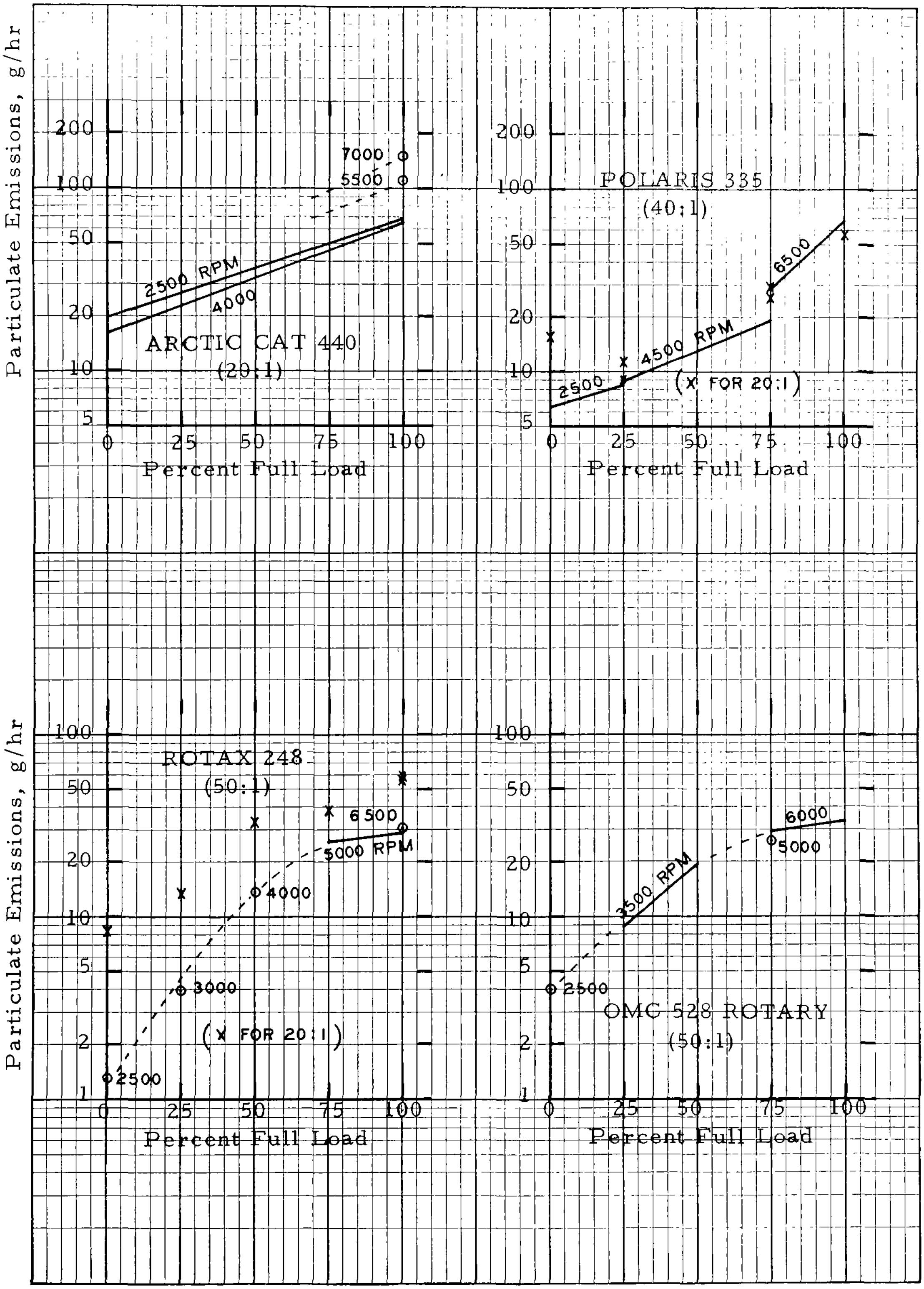

FIGURE 17. PARTICULATE EMISSIONS FROM FOUR SNOWMOBILE ENGINES AS FUNCTIONS OF LOAD, WITH ENGINE SPEED AS PARAMETER DATA FROM TABLES 5, 7, 8, AND 9

smoke plumes, these opacity values may not relate to plume visibility the same way as for black smoke[15]. In particular, white smoke may be more visible than black smoke for a given opacity value. This difference might be attributed to contrast with background, or more probably, to the stronger angular scattering exhibited by white smoke[16].

The smoke data are summarized in Table 11, with each average value representing two to four original data points. Smoke values showed a great deal of variability, but there is a general trend toward higher opacity values for higher oil concentrations. To document the appearance of smoke from snowmobile engines, Figures 18 through 20 show three different levels. Figure 18 shows smoke measured at 8 percent opacity as viewed in bright, direct sunlight. Figure 19 shows smoke measured at 14 percent opacity as viewed under overcast conditions. These photographs also show the difficulty in making an objective visual smoke evaluation where ambient light conditions, viewing angle, and background are not constant. The smoke being emitted was generally somewhat more visible than the photographs make it appear, possibly due to absence of color in the photos and the ability of the eye to see smoke puffs better than the still camera. The limit of visibility appeared to be about 2 to 3 percent opacity, with lower levels being indistinguishable from the background. Figure 20 shows smoke measured at 2 percent opacity in bright, direct sunlight, with the small contrast within the ring being its only visible point. The pipe shown in the photos was a 4 foot extension of 2 inch diameter, and about 4 feet of 3- or 4-inch pipe connected it to the engines' mufflers. The pipe probably had little effect on the smoke readings due to its short length.

TABLE 11. SUMMARY OF AVERAGE SMOKE OPACITY FROM 2-STROKE SNOWMOBILE ENGINES, BASED ON 2-INCH DIAMETER OUTLET

Arctic Cat 440		
Condition		% Opacity
rpm	Load	20:1 Mix
1560	Idle	1.9
2500	0	2.7
2500	1/2	4.3
2500	full	20.
4000	0	1.0
4000	1/2	0.5
4000	full	0.5
5500	0	2.9
5500	1/2	2.1
5500	full	0.8
7000	0	1.7
7000	1/2	0.5
7000	full	0.7

Polaris 335			
Condition		% Opacity	
rpm	Load	20:1 Mix	40:1 Mix
1010	Idle	0.4	0.2
2500	0	1.4	0.8
2500	1/2	2.0	1.1
2500	full	4.5	1.9
4500	0	0.9	0.3
4500	1/2	0.8	0.4
4500	full	11.	1.4
5500	0	1.4	1.0
5500	1/2	9.	0.8
5500	full	1.2	1.0
6500	0	2.2	1.4
6500	1/2	0.8	0.9
6500	full	1.6	1.0

Rotax 248			
Condition		% Opacity	
rpm	Load	20:1 Mix	50:1 Mix
1850	Idle	3.0	1.1
2500	0	4.2	1.3
2500	1/2	16.	2.0
3000	0	3.8	1.4
3000	1/2	12.	3.3
3000	full	25.	8.3
4000	1/2	7.5	2.4
4000	full	12.	4.7
5000	0	3.0	1.1
5000	1/2	3.	1.3
5000	full	7.	2.1
6500	1/2	1.	0.9

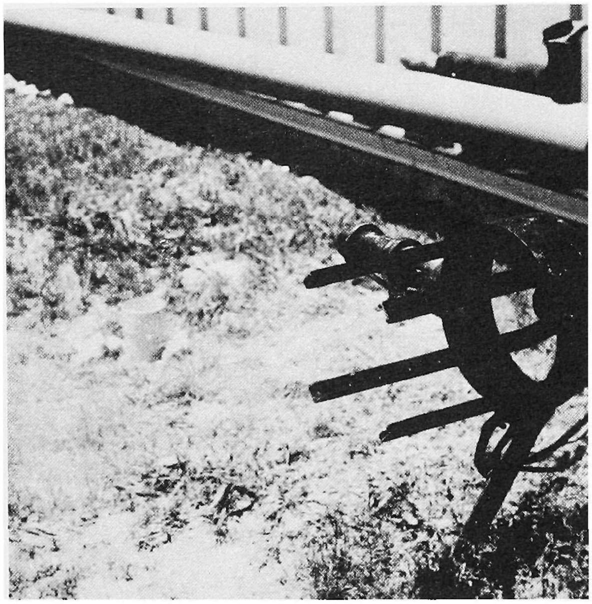

FIGURE 18. 8% OPACITY SMOKE FROM A SNOWMOBILE ENGINE

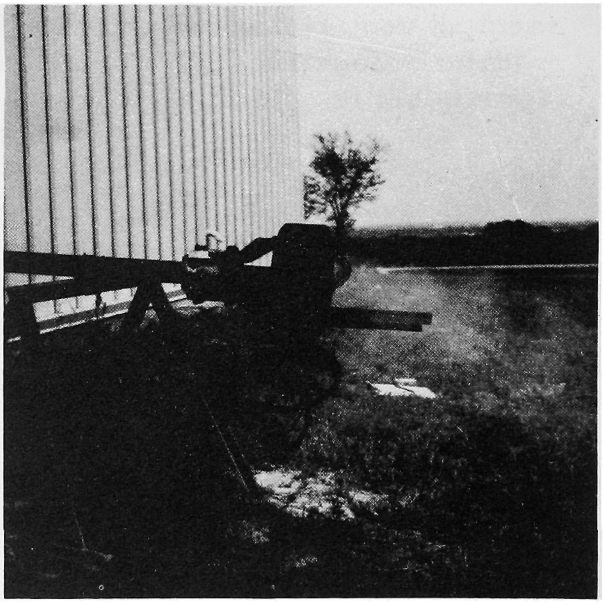

FIGURE 19. 14% OPACITY SMOKE FROM A SNOWMOBILE ENGINE

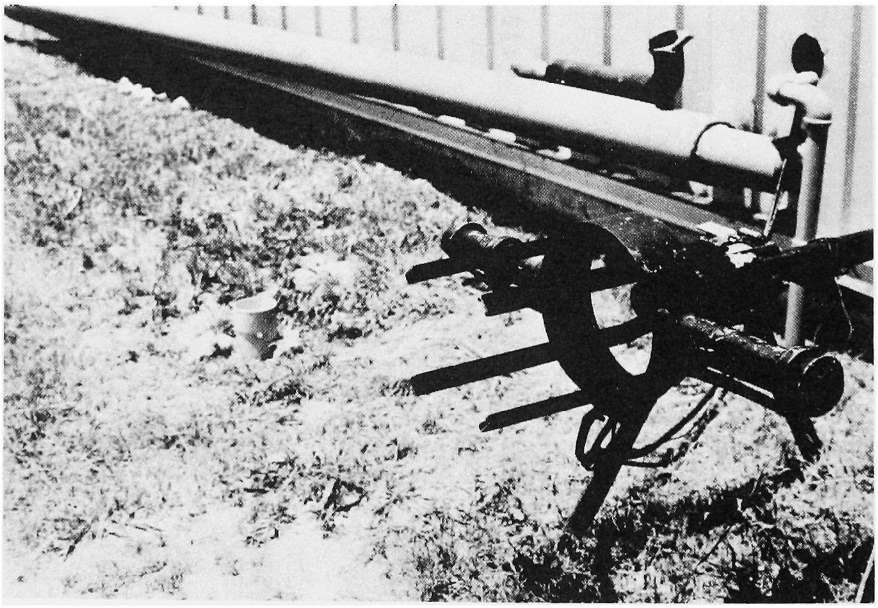

FIGURE 20. 2% OPACITY SMOKE FROM A SNOWMOBILE ENGINE

V. ESTIMATION OF EMISSION FACTORS AND NATIONAL IMPACT

In order to develop emission factors for snowmobiles, mass emission rates must be known, and operating cycles representative of usage in the field must be either known or assumed. Extending applicability of data on a few engines to the population requires additional input on the composition of the snowmobile population by size and type. It is also necessary to have data on annual usage and total machine population when national emissions impact is estimated.

A. Development of Emission Factors

Operating data on snowmobiles are somewhat limited, but enough are available so that an attempt can be made to construct a representative operating cycle for the purposes of this report. The required end products of this effort are time-based weighting factors for the speed/load conditions at which the test engines were operated; and use of these factors will permit computation of "cycle composite" mass emissions, power, fuel consumption, and specific emissions.

Since the operating data and other information on normal snowmobile driving patterns comes from a variety of sources, a summary will be made so that the validity of assumptions made later can be assessed. Table 12 shows dynamometer operating cycles used by two manufacturers (Polaris[17] and John Deere[18]), indicating high overall load factors,

TABLE 12. DYNAMOMETER OPERATING CYCLES USED BY TWO MANUFACTURERS

Polaris Data[17]			John Deere Data[18]		
rpm	Throttle Opening	% of Time	rpm	Throttle Opening	% of Time
1500	0	13.2	2500	0	28.6
3500	1/4	13.2	5000	1/4	22.7
4500	1/2	15.8	6500	1/2	18.1
5000	3/4	17.1	6500	3/4	2.9
6000	full	35.5	6500	full	27.6
6500	full	2.6			
7000	full	1.3			
7500	full	1.3			

and these cycles are presumably used for accelerated-stress testing of engines and/or driveline components. It is doubtful that they represent field operation accurately, and they probably are not intended to do so. Table 13 presents estimates from Massey-Ferguson (Ski-Whiz)[19], obtained through test experience and customer use contacts. These

TABLE 13. ESTIMATES OF AVERAGE OWNER USAGE FROM MASSEY-FERGUSON

Throttle Opening	Owners from Northern Regions and in Mountains	Owners from Metro. Areas Spending Weekends North
Idle	5	5
1/4	30	35
1/2	45	35
3/4	15	20
full	5	5

		% of Operating Time for	
Speed, mph	Conditions	Owners from Northern Regions and in Mountains	Owners from Metro. Areas Spending Weekends North
15	Trail Riding	40	60
15	Heavy Lugging in Wet Snow & Towing Sleds	5	5
20	Breaking Trails in Fresh Snow	20	10
20	Hill Climbing	10	5
35	Operating on Lakes and Packed Snow	20	15
50	High Speed Operation	5	5

estimates indicate a division in rider habits depending ostensibly on area of residence but perhaps actually depending on rider experience or the types of use the riders make of their sleds (purely recreational for the metropolitan group versus recreational plus utilitarian for the northern/ mountain group).

In addition to the tabular data already presented, several sources have made generalizations on snowmobile operation, such as, "The snowmobile's variable-speed transmission is such that almost all loaded operation occurs between 4000 and 5500 rpm".[20] Another source said that snowmobiles "...are operated in a range from 4500 to 6000 rpm with a bulk of the running in the 5000 to 5500 rpm range".[21]

The final item of operating data[22], and the most useful, is shown in Table 14. This tabulation shows percentage of operating time as a function of both engine rpm and throttle position for data taken on three snowmobiles operating at high altitude in the Colorado Rockies.

TABLE 14. FIELD USAGE DATA DEVELOPED BY JOHN DEERE

	% of Operating Time at Throttle Opening (%) and rpm									
rpm	0-9%	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-100%
0- 499	0.17	----	----	----	----	----	----	----	----	----
500- 999	0.04	----	----	----	----	----	----	----	----	----
1000-1499	----	----	----	----	----	----	----	----	----	----
1500-1999	----	----	----	----	----	----	----	----	----	----
2000-2499	----	----	----	----	----	----	----	----	----	----
2500-2999	----	----	----	----	----	----	----	----	----	----
3000-3499	0.45	0.21	----	----	----	----	----	----	0.01	----
3500-3999	4.38	3.67	0.22	0.09	0.04	0.02	0.02	0.02	0.01	0.02
4000-4499	5.05	6.05	0.94	0.44	0.21	0.20	0.14	0.13	0.09	0.05
4500-4999	5.59	7.90	1.86	0.61	0.31	0.28	0.22	0.25	0.19	0.16
5000-5499	6.04	10.23	5.82	2.06	0.66	0.48	0.36	0.37	0.18	0.09
5500-5999	0.64	3.84	6.72	5.20	2.19	1.14	0.99	0.86	0.95	0.13
6000-6499	0.02	0.09	0.73	1.69	1.72	1.38	1.27	1.28	1.28	0.34
6500-6999	----	----	----	0.03	0.08	0.09	0.09	0.14	0.14	0.01

These data were carefully qualified by John Deere regarding possible lack of applicability to average snowmobile operation, but at this point they represent the only available quantitative information acquired under field conditions. Since no better information is available at present, the John Deere data in Table 14, modified where necessary, have been chosen to form the basis for a snowmobile duty cycle applicable to the test engines.

The first modification of the Table 14 data necessary for the purposes of this report is to regroup the percentages of operating time on intervals corresponding to load increments used in this study. At the same time, the rpm intervals have been combined into 1000 rpm increments; and an arbitrary 10 percent has been included as idle time. These modifications result in the data shown in Table 15; and it should be noted that the rpm increment centered on 3500 rpm includes the interval 3000-3999 rpm, and so forth for the other categories.

The test procedure used for each test engine was somewhat different than those used for the others, both in selection of operating speeds

TABLE 15. REGROUPED AND MODIFIED FIELD USAGE DATA

Load	% of Operating Time at rpm and Load					Subtotals
	Idle	3500 rpm	4500 rpm	5500 rpm	6500 rpm	
full	----	---	0.1	0.1	0.2	0.4
7/8	----	---	0.3	1.0	1.3	2.6
3/4	----	---	0.6	2.2	2.4	5.2
1/2	----	0.1	1.3	6.0	3.6	11.0
1/4	----	0.7	4.8	17.9	1.8	25.2
1/8	----	4.7	14.7	13.5	0.1	33.0
0	10.0	3.0	6.0	3.8	---	22.8
Subtotals	10.0	8.5	28.1	44.5	9.4	

and the loads used in conjunction with those speeds, as shown in Table 2. These differences made it necessary to modify the data in Table 15 somewhat for each engine, reflecting the various speed/load conditions used. The time-based weighting factors generated by this process are given in Table 16, and these factors are the ones which will be used in determining emission factors. To explain some of the deviations of the weighting factors in Table 16 from the data in Table 15, it should be noted that the speed range (above idle) for each engine is somewhat different, making the speed subtotals vary from engine to engine. Again on speed subtotals, the Rotax is weighted more heavily toward maximum rpm than the other engines because power output was more strongly dependent on speed for the Rotax than for the other engines near maximum speed. The larger weights given the maximum speed (6500 rpm) had the effect of increasing the composite load factor without undue increases in the weighting factors for the high-load conditions.

Looking at the load subtotals, those for the Arctic 440 and the OMC 528 Rotary are fairly close to those for the field data in Table 15. The subtotals for 1/4, 1/8, and zero loads on the Polaris and Rotax, however, show higher factors at 1/4 and zero loads and a lower factor at 1/8 load. This discrepancy is due to omission of the 1/8 load condition from the schedules of the Polaris and Rotax at several speeds, which was the result of the apparently inaccurate assumption that this condition was not important in the duty cycle. The omission was compensated for by increasing the weights of the 1/4 load and zero load conditions in such a way as to keep the composite horsepower (or load factor) constant. The higher load conditions for the Rotax were given somewhat more weight than those for the other engines because the weight/power ratio for the Bombardier Elan 250T (which uses the Rotax 248) is about 31 lb_f/hp (loaded), as compared to a range of 19-22 for machines in which the other three engines are used.

TABLE 16. TIME-BASED WEIGHTING FACTORS FOR SNOWMOBILE ENGINE EMISSIONS RESULTS

Load	Arctic 440-% Time at rpm & Load Idle	2500	4000	5500	7000	Subtotals
full	**	----	----	----	1	1
7/8	**	----	----	1	2	3
3/4	**	----	----	2	2	4
1/2	**	----	1	6	4	11
1/4	**	----	2	20	3	25
1/8	**	2	15	18	1	36
0	10	1	6	3	----	20
Subtotals	10	3	24	50	13	

Load	Polaris 335 - % Time at rpm & Load Idle	2500	3500	4500	5500	6500	7000	Subtotals
full	**	*	----	----	----	1	1	2
7/8	**	*	*	*	1	1	1	3
3/4	**	*	----	1	2	2	----	5
1/2	**	*	----	1	5	4	*	10
1/4	**	----	1	15	26	*	*	42
1/8	**	2	4	*	*	*	*	6
0	10	1	3	10	8	----	**	32
Subtotals	10	3	8	27	42	8	2	

Load	Rotax 248 - % Time at rpm & Load Idle	2500	3000	4000	5000	6500	Subtotals
full	**	**	**	----	1	2	3
7/8	**	**	**	----	1	5	6
3/4	**	**	----	1	2	5	8
1/2	**	----	----	2	5	5	12
1/4	**	----	1	5	16	5	27
1/8	**	2	4	14	*	*	20
0	10	1	2	5	6	----	24
Subtotals	10	3	7	27	31	22	

Load	OMC 528 Rotary - % Time at rpm&Load Idle	2500	3500	4000	5000	6000	Subtotals
full	**	**	**	----	1	1	2
7/8	**	**	**	----	1	1	2
3/4	**	**	----	1	2	2	5
1/2	**	----	----	*	5	3	8
1/4	**	----	1	5	17	2	25
1/8	**	*	5	13	13	*	31
0	10	3	4	6	4	----	27
Subtotals	10	3	10	25	43	9	

* No data taken

** No data taken, and point computed to have zero weight

Earlier in the report, it was noted that the Arctic 440 engine was subjected to a special set of runs intended to assess emissions changes when the carburetor high-speed jet was set richer than normal. This change in jet setting is a recommended field adjustment when operating temperatures get too high, and the data obtained under rich conditions were presented in Table 6. Since the "rich" data were acquired at relatively few operating conditions, it was necessary to modify the weighting factors shown in Table 16 somewhat to apply to the Table 6 data. The aim of the changes was to keep the load factor as constant as possible using available data points, and this goal was essentially accomplished. These same comments apply in general to emissions of aldehydes and particulate from all the test engines.

Based on calculation techniques from Section III. D. and data from Tables 5 through 9 and 16, composite mass emissions and composite brake specific emissions were calculated for the four snowmobile engines tested (including the "rich" runs on the Arctic 440). These data are presented in Table 17 along with calculated composite power outputs, load factors on fuel and power bases, and fuel rates. These composite results show considerable variation from engine to engine, but it appears that most of the variations can be explained by examining design and tuning differences in the engines.

To begin, the most obvious design differences are between the three 2-stroke engines (as a group) and the rotary. The absence of fuel short-circuiting in the rotary as compared to the 2-strokes explains the rotary's lower specific hydrocarbon emissions; and this same feature had some effect on particulate emissions, also. The combustion process in the rotary appears more like that in a 4-stroke engine than that in a 2-stroke engine. This same design difference contributed to the higher CO and SO_x emissions of the rotary, since a greater fraction of the fuel charge was being burned in the rotary.

The major variations between the individual 2-stroke engines can probably be explained by (1) the relatively lean mixture used by the Arctic (in stock configuration), as compared to the Polaris and the Rotax; and (2) the high delivery ratio used in the Rotax, as compared to the Arctic and the Polaris. The first of these explanations had a lot to do with the Arctic's low CO, HC, and RCHO (compared to the Polaris). Note that mixture was singled out as a causative factor because the Arctic and Polaris were otherwise quite similar (specific output, compression ratio, and delivery ratio/port timing as determined by fractions of fuel short-circuited). Additional credence is lent to this deduction by the fact that the Arctic engine consistently ran hotter than the Polaris under similar conditions.

TABLE 17. CYCLE COMPOSITE MASS AND SPECIFIC EMISSIONS FOR FOUR SNOWMOBILE ENGINES

Engine	Load Factors		Composite Fuel Rate		Composite Emissions, g/hr					
	Power	Fuel	lb_m/hr	[a]gal/hr	HC	CO	NO_x	RCHO	[c]Part	[b]SO_x
Arctic 440	0.204	0.240	5.60	0.90	567	909	9.15	5.7	38.1	0.85
Arctic 440 (Rich)	0.211	0.265	6.81	1.10	701	1720	6.18	----	----	1.02
Polaris 335	0.212	0.265	6.33	1.02	662	1310	10.1	14.	13.8	0.95
Rotax 248	0.233	0.353	4.66	0.75	739	238	12.7	5.3	9.40	0.59
OMC 528 Rotary	0.217	0.345	9.57	1.54	145	2510	21.2	----	10.2	1.81

Engine	Composite		Composite Specific Emissions, g/hp-hr					
	Power, hp	Fuel Cons., lb_m/hp-hr	HC	CO	NO_x	RCHO	[c]Part	[b]SO_x
Arctic 440	6.40	0.88	88.6	142.	1.43	0.88	6.13	0.13
Arctic 440 (Rich)	6.38	1.07	110.	270.	0.97	----	----	0.16
Polaris 335	5.59	1.13	118.	235.	1.81	2.5	2.50	0.17
Rotax 248	3.78	1.23	196.	63.0	3.36	1.5	2.60	0.16
OMC 528 Rotary	7.05	1.36	20.6	356.	3.01	----	1.50	0.26

[a]Assuming 6.2 lb_m/gal
[b]Calculated from fuel consumption assuming 0.043 percent by weight fuel sulfur content(23)
[c]Based on gasoline:oil ratios of 20:1 for the Arctic, 40:1 for the Polaris, and 50:1 for the Rotax and the OMC

The second of the two explanations is probably responsible for the relatively high HC and NO_x and the relatively low CO emitted by the Rotax. The high delivery ratio (diagnosed by the 35 percent of fuel short-circuited by the Rotax, compared to 23 percent for the Arctic and Polaris) probably contributed to the high HC directly, and indirectly to the low CO and high NO_x, because the cylinders were probably scavenged more completely than those of the other two engines. The high delivery ratio also contributed to the much cooler running of the Rotax as compared to the Artic and Polaris.

The particulate results tend to confirm several points in the foregoing analysis. First, the much higher specific value for the Arctic (even through it ran on a leaner mixture) can be traced to the 20:1 gasoline:oil mixture recommended for it, as compared to 40:1 for the Polaris and 50:1 for the Rotax. In addition, the contribution of fuel short-circuiting to particulate emissions is emphasized by the higher specific particulate value for the Rotax as compared to the Polaris, even though the latter used a higher oil concentration.

The special runs on the Arctic 440 using a richer-than-normal high-speed jet setting resulted in the expected outcome, namely, lower NO_x (and lower operating temperatures) and higher HC and CO. The fraction of fuel short-circuited was the same for both sets of runs on the Arctic.

The power-based load factors shown in Table 17 are fairly close for all the engines, but there is a slight variation (intentionally) related to the weight/power ratios of the machines in which the engines are used. The degree of difference between the power-based and fuel-based load factors for a particular engine reflect the difference in specific fuel consumption between the maximum-power condition and the conditions under which the engines are assumed to be operated in service. In order to gain an understanding of the variation in emissions and fuel consumption with load factor, two other operating cycles were constructed for each engine. These alternate cycles both had higher load factors, and the results of this analysis are presented in Table 18. The alternate cycles are composed of the same speed/load conditions as used to make up the cycles shown in Table 16, but with more weight given the higher power conditions.

The cycles based on higher load factors generally produced higher mass emissions, except for CO from the Rotax and HC from the rotary (both of which were quite minimal to begin with). Specific emissions varied less strongly with changes in operating cycles,and exhibited both increases and decreases with increasing load factor, depending on the particular engine and constituent being considered. Fuel consumption increased with increasing load factor in all cases; but specific fuel consumption generally decreased, indicating that operating conditions nearer to maximum power were being used a greater percentage of the time.

TABLE 18. VARIATION IN MAJOR EMISSIONS AND FUEL CONSUMPTION WITH OPERATING CYCLE LOAD FACTOR

		Composite										
		Load	Fuel Rate		Fuel Cons.,	Power,	Mass Emissions, g/hr			Specific Emissions, g/hp-hr		
Engine	Cycle	Factor	lb_m/hr	gal/hr	lb_m/hp-hr	hp	HC	CO	NO_x	HC	CO	NO_x
Arctic 440	From Table 16	0.204	5.60	0.90	0.88	6.40	567	909.	9.15	88.6	142.	1.43
	Alternate A	0.326	7.43	1.20	0.73	10.2	904.	1910.	19.0	88.6	187.	1.86
	Alternate B	0.438	10.3	1.66	0.75	13.7	1200.	2490.	29.0	87.6	182.	2.12
Polaris 335	From Table 16	0.212	6.33	1.02	1.13	5.59	662.	1310.	10.1	118.	235.	1.81
	Alternate A	0.333	7.95	1.28	0.90	8.80	868.	1710	17.7	98.6	194.	2.01
	Alternate B	0.455	10.4	1.68	0.87	12.0	1230.	2290.	28.8	102.	191.	2.40
Rotax 248	From Table 16	0.233	4.66	0.75	1.23	3.78	739.	238.	12.7	196.	63.0	3.36
	Alternate A	0.337	5.47	0.88	1.00	5.46	860.	205.	18.9	158.	37.5	3.46
	Alternate B	0.481	7.33	1.18	0.94	7.79	1160.	275.	30.7	149.	35.3	3.94
OMC 528 Rotary	From Table 16	0.217	9.57	1.54	1.36	7.05	145.	2510.	21.2	20.6	356.	3.01
	Alternate A	0.307	9.98	1.61	0.98	10.2	171.	2700.	25.4	16.8	265.	2.49
	Alternate B	0.416	12.5	2.02	0.90	13.9	155.	3610.	34.4	11.2	260.	2.47

The data in Table 18 generally support the choice of the John Deere operating data[22] as the basis for the assumed operating cycle for the purposes of this report. The primary factor involved is the fuel consumption, which seems quite a bit more reasonable for the "Table 16" cycles than for either of the alternates. The lowest set of fuel consumption figures gives an average operating time for machines using the test engines of 5.3 hours per tank of fuel, while the middle set yields 4.3 hours and the highest set 3.3 hours.

The total engine power required to propel a snowmobile under any set of conditions can be considered as

power = (velocity)(total drag/drive train efficiency).

The "total drag" term in this equation is composed of an undefined mixture of forces including sliding friction, air resistance, rolling resistance of the track/snow interface, force required to displace parts of the snow surface, and possibly others. Some of these forces may be essentially independent of velocity (V), while others are proportional to V^2 or perhaps even higher powers of V. As a result, the power to propel a snowmobile is proportional to velocity raised to some power, probably between 1 and 3 (power $\propto V^1$ would be analogous to low-speed sliding friction, while power $\propto V^3$ would be roughly analogous to a displacement-hull ship, a fan, or an automobile). Losses in the drive train also vary with rotational speed of the components. These ideas and some assumptions about snowmobile ground speeds can lead to a (simplified) calculated load factor which can be compared to those shown in Table 18.

Referring back to data presented in Table 13[19], an average speed for each category of snowmobile usage can be calculated from the bottom set of numbers; and these averages turn out to be 22.2 mph for "Northern" owners and 20.5 mph for "Metropolitan" owners. If the average of these two numbers (21.4 mph) is considered typical, and if a typical snowmobile's top speed can be estimated at 45 mph, then it remains only to choose a velocity exponent as described above to calculate a load factor based on operating speed. In mathematical terms

$$\text{estimated load factor} = (21.4\ \text{mph}/45\ \text{mph})^x,$$

where x is the velocity exponent. Based on experience with other types of machines, the best estimate for the velocity exponent is 2.0; less than that for a planing-hull boat (2.5) but greater than that for a simple sliding block (1.0). Inserting this estimate into the equation above yields

$$\text{estimated load factor} = (21.4\ \text{mph}/45\ \text{mph})^{2.0} = 0.226,$$

which is quite close to the 0.216 average load factor for the assumed operating cycle. If the exponent chosen had been 1.8, the calculated load factor would be 0.262. If the exponent had been 2.2, the load factor would be 0.195. Consequently, small changes in the velocity exponent do not alter the conclusion that the operating cycle given in Table 16 is more representative than the alternate cycles. It is conceded that the derivation of the assumed operating cycle is not rigorous, but in the absence of more comprehensive data on field operation, it is the best effort possible within the scope of the subject contract.

To arrive at emission factors which have a degree of applicability to the snowmobile population as a whole, the logical starting point is to reiterate available data on the composition of that population. Considering machines in service as of the 1972-1973 season, the OMC rotary engine is a minor factor, with approximately 5000 units in the field (or about 0.34 percent, as will be shown later). The best estimates of a population breakdown by size and other pertinent quantities comes from a survey of magazine subscribers(1), which generated data shown in Table 19. Some

TABLE 19. DESCRIPTION OF SNOWMOBILES OWNED AND OPERATING DATA OBTAINED FROM A SURVEY OF MAGAZINE SUBSCRIBERS

Engine Sizes

Displ., cm^3	% of Owners
0-295	22.5
296-340	27.8
341-400	27.0
401-600	17.7
601 & up	5.1

Brand Ownership (Engine)

Brand	% of Owners
Ski-Doo (Rotax)	31.7
Arctic Cat (own)	23.4
Polaris (own)	6.9
Sno-Jet (Yam.)	6.2
Rupp (own)	5.4
Moto-Ski (BSE)	4.9
Scorpion (CCW, JLO)	4.9
Others	16.6

Age of Machines

Model Year	% of Owners
1972	24.9
1971	29.4
1970	21.8
1969	12.3
1968	7.4
1967 & prior	4.2

Fuel Mixtures

Ratio	% of Owners
20:1	69.3
24:1	16.4
40:1	17.9
50:1	2.4

Machine Usage	
Time	14 hr/wk
Single Riding	75%
Double Riding	25%

Consumption per Week	
Gasoline	11.8 gal
Oil	2.4 qt
*Total Fuel	12.4 gal

*Sum of gasoline and oil

of these data, especially machine usage and fuel consumption, should probably be qualified because the survey respondents may be considerably more active in snowmobiling than the average owner. Since both usage and fuel consumption were from the same sample of people, however, a comparison of the two should be valid. This comparison yields an average fuel consumption of 0.89 gal/hr.

To arrive at a reasonable estimate for machine size, an average displacement will be assumed for each displacement class in the table. These assumptions are $250cm^3$ for the $0\text{-}295cm^3$ class, 325 for the 296-340 class, 390 for the 341-400 class, 440 for the 401-600 class, and $630cm^3$ for $601cm^3$ and over class. Weighting the assumptions by owner percentages from Table 19 yields an estimated average displacement of $362cm^3$. Since a breakdown of the snowmobile population in terms of rated power is not available, mass emissions will be restated in terms of engine displacement; and characteristic emissions for 2-stroke snowmobile engines will be estimated on that basis.

Table 20 shows the results of dividing mass emissions, fuel consumption, and power output from 2-strokes by engine displacement. The last line of the table also shows data resulting from taking a weighted mean of the data on individual engines. The weights used reflect the degree to which each engine is assumed to be representative of the population of engines in service, not the relative popularity of the engines in the marketplace. A relatively small weight was given to the Rotax 248 data, because the high delivery ratio of this engine made its emissions quite different from engines considered more typical of those in service. The weighted means in Table 20 are considered to be as representative as possible of snowmobile engines in the field, so they can be considered as estimates of characteristic snowmobile emissions for the purposes of this report. Applying these estimates to the previously-approximated average displacement of $362cm^3$ yields the estimated snowmobile emission factors given in Table 21 and an estimated average fuel consumption of 0.94 gal/hr (very similar to the 0.89 gal/hr figure calculated from the data in Table 19[1]). The mass emission rates given in Table 17 for the OMC rotary will be assumed applicable to snowmobiles employing that engine.

B. Estimation of National Impact

To compute a figure for snowmobile emissions on a national basis, it is necessary to know not only the emission factors but also total number of machines in service and annual operating time. Commenting on the latter item first, one figure perhaps indicative of annual usage has already been given in Table 19, namely, 14 hours per week average obtained from a survey of magazine subscribers[1]. This value, as already mentioned, is probably higher than the overall average because the subscribers are probably more enthusiastic about their snowmobiling than the average owner.

TABLE 20. EMISSIONS, FUEL CONSUMPTION, AND POWER OUTPUT OF 2-STROKE SNOWMOBILE ENGINES DIVIDED BY ENGINE DISPLACEMENT

Engine (Displ., cm^3)	Composite Power/Displ., hp/liter Displ.	Fuel Cons./Displ., gal/(hr)(liter Displ.)	Emissions/Displ., g/(hr)(liter Displ.)					
			HC	CO	NO_x	RCHO	Part.	SO_x
Arctic 440 (436)	14.7	2.06	1300.	2080.	21.0	13.	87.4	1.95
Polaris 335 (335)	16.7	3.04	1980.	3910.	30.1	42.	41.2	2.84
Rotax 248 (247)	15.3	3.04	2990.	964.	51.4	21.	38.1	2.39
* Weighted Mean	15.8	2.59	1740.	2700.	27.7	25.	**77.1	2.35

* Weights are 0.5 for the Arctic, 0.4 for the Polaris, 0.1 for the Rotax (except particulate)
** Based on mixture data from Table 19, weights for particulate were: Arctic--0.78, Polaris--0.20, Rotax--0.02 (after correcting for multiple answers, 78% of owners report approx. 20:1, 28% report 40:1, and 2% report 50:1)

TABLE 21. ESTIMATED SNOWMOBILE EMISSION FACTORS (ASSUMING 362 cm^3 DISPLACEMENT)

Emission Factors in g/hr					
HC	CO	NO_x	RCHO	Part.	SO_x
630.	978.	10.0	9.2	27.9	0.85

Emission Factors in g/gal Fuel Consumed*					
HC	CO	NO_x	RCHO	Part.	SO_x
670.	1000.	11.	9.8	30.	0.90

* Assuming fuel consumption of 0.94 gal/hr

Information submitted to ISIA by Massey-Ferguson[19] (Ski-Whiz) is summarized in Table 22, indicating about 50 to 100 hours' usage per year depending on the type of service expected of the machine. Mr. John F. Nesbitt, Director of Engineering of ISIA, reports that 100 hr/year was a figure used previously but that 50 hr/year is now believed to be more accurate[24].

TABLE 22. ESTIMATES OF ANNUAL OPERATING TIME FROM MASSEY-FERGUSON

Time Period	Hours of Usage: Owners from Northern Regions and in Mountains	Hours of Usage: Owners from Metropolitan Areas Spending Weekends North
Day of Usage	3	4
Week of Usage	8	6
Year of Usage	100	50

Most snowmobiles are in the "snow belt" region, defined as the area where there is 1 inch or more of snow on the ground for at least 80 days per year[25]. The season for snowmobile usage, then, is at least 12 weeks long in most cases, which means that the 14 hr/week estimate from Table 19[1] could translate into as much as 168 hr/year. Likewise, the weekly estimates from Table 22[19] could easily mean 72 hr/year to 96 hr/year (or more, considering the longer season in the northern regions and mountains). Usage cannot be resolved quantitatively from such figures, so an assumption must be made to permit impact computation until such time as real usage data are acquired. This assumption will be that snowmobiles are operated an average of 60 hours per year.

Total snowmobile population is a more accurately-known figure, because most states require registration. Data on registrations[26] are presented in Table 23 and were supplied through Mr. Nesbitt of ISIA. The most notable features of these registration data are that the total is almost 1.5 million sleds in the U.S., that over 70 percent of the snowmobiles are registered in just four states (Michigan, Minnesota, Wisconsin, and New York), and that only about 12 percent of all snowmobiles are found in areas outside the northeast and northern midwest.

For immediate purposes, the important figure is the total registration figure of 1.46 million, which will be assumed to be the total population of snowmobiles in use during the 1972-1973 season for the purposes of this report. Based on this assumption, the estimated average annual usage figure of 60 hours, and emissions data from Tables 17 and

TABLE 23. DISTRIBUTION OF REGISTRATIONS FOR THE 1972-1973 SEASON

State	State Total	Percent of U.S. Registrations	State	State Total	Percent of U.S. Registrations
Michigan	368,956	25.2	Idaho	14,000	1.0
Minnesota	328,246	22.4	Utah	12,000	0.8
Wisconsin	196,837	13.5	Connecticut	11,963	0.8
New York	135,487	9.3	Washington	10,500	0.7
Maine	65,607	4.5	Alaska	7,580	0.5
Massachusetts	44,000	3.0	Indiana	7,500	0.5
New Hampshire	43,197	3.0	California	6,470	0.4
Vermont	35,000	2.4	Wyoming	6,000	0.4
Illinois	28,500	1.9	South Dakota	6,000	0.4
Iowa	27,000	1.8	Oregon	5,161	0.4
North Dakota	21,000	1.4	New Mexico	1,235	0.1
Montana	15,914	1.1	Nebraska	325	---
Colorado	14,200	1.0	*Pennsylvania	55,000	3.8

U.S. Total	1,462,678
Canada Total	517,132

* Estimated

21, national emissions impact has been calculated and appears as Table 24. An assessment of the national importance of these emissions can

TABLE 24. ESTIMATED NATIONAL EMISSIONS IMPACT OF SNOWMOBILES

Pollutant	g/unit Year	Tons Emitted per Year
HC	37,800	60,900
CO	58,700	94,600
NO_x	600	967
RCHO	552	890
Particulate	1,670	2,700
*SO_x	51	82

*Calculated on the basis of fuel consumption and sulfur content of 0.043 percent by weight

be made by comparing them to revised EPA Nationwide Air Pollutant Inventory data[27], which has been done in Table 25. This comparison shows snowmobile emissions to be minimal on a national basis, but effects in more limited areas cannot be neglected.

TABLE 25. COMPARISON OF SNOWMOBILE EMISSION ESTIMATES WITH EPA NATIONWIDE AIR POLLUTANT INVENTORY DATA

	1970 EPA Inventory Data, 10^6 tons/yr[27] (Revised)		Snowmobile Estimates as % of	
Pollutant	All Sources	Mobile Sources	All Sources	Mobile Sources
HC	27.3	15.2	0.223	0.401
CO	100.7	78.1	0.094	0.121
NO_x	22.1	11.0	0.004	0.009
Particulate	33.4	1.0	0.008	0.270
SO_x	25.5	0.9	0.0003	0.009

Since most snowmobile operation occurs in just a few states and mostly during three or four months of the year, the possible importance of these machines as a localized source of pollutants cannot be discounted. In particular, localized concentrations of CO and HC could rise significantly where a number of machines are operated in a restricted area. In most cases, areas of concentrated activity are probably rural rather than urban due to space requirements.

A summary of estimated variation in snowmobile emissions by season and region is given in Table 26. The northern region includes the

TABLE 26. SUMMARY OF ESTIMATED SEASONAL AND REGIONAL VARIATION IN SNOWMOBILE EMISSIONS

Region	Percentage of Total Emissions by Season				Subtotals
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	
Northern	55.8	18.6	0.0	18.6	93.0
Central	7.0	0.0	0.0	0.0	7.0
Southern	0.0	0.0	0.0	0.0	0.0
Subtotals	62.8	18.6	0.0	18.6	100.0

area between 49° and 43° North latitude, the central region is between 43° and 37°, and the southern region is between 37° and 31°. The basic breakdown comes from assuming a 5-month snow season in the northern region, a 3-month season in the central, and no season in the southern region. The other major variable considered is geographic distribution of snowmobiles (by states), according to data from Table 23. It was assumed that most snowmobiling is done in the state and region in which the machine is registered, but operation was assumed to be in another state or region where such an occurrence seemed obvious. One example would be New York state, which is placed in the central region by its population center, but in which most snowmobile operation is probably in the northern half (or in the northern region as defined here). Grass racing and other summer activities have not been considered.

Regarding concurrence with emissions released by other sources, snowmobiles probably emit only very small amounts in most urban areas or during peak traffic hours. In these respects, snowmobile emissions can hardly be considered additive to other emissions in estimating contributions to most urban air pollution episodes.

VI. SUMMARY

This report is the end product of a study on exhaust emissions from snowmobile engines, and it is Part 7 of a seven-part final report on "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Contract EHS 70-108. It includes test data, documentation, and discussion on detailed emissions characterization of four engines (three 2-stroke twins and one rotary), as well as estimated emission factors and national emissions impact. As a part of the final report on the characterization phase of EHS 70-108, this report does not include information on aircraft turbine emissions, outboard motor crankcase drainage, or locomotive emissions control technology. As required by the contract, these three latter areas have been or will be reported on separately.

The emission measurements on the four snowmobile engines were conducted in, and by the staff of, the Emissions Research Laboratory. Data were acquired during steady-state "mapping" procedures, which included idle conditions and 28 other speed/load combinations, not all of which were the same for any two engines.

The exhaust products measured included total hydrocarbons by FIA; CO, CO_2, NO, and hydrocarbons by NDIR; NO and NO_x by chemiluminescence; O_2 by electrochemical analysis; light hydrocarbons by gas chromatograph; aldehydes by wet chemistry; particulates by gravimetric analysis; and smoke by the PHS light extinction smokemeter. The engines were operated with (nominal) 20°F intake air, fuel losses by evaporation (in the field) were considered negligible, and SO_x emissions were calculated rather than being measured. Emission factors and national impact were computed for hydrocarbons (total), CO, NO_x, RCHO (aldehydes), particulate, and SO_x.

Expressing snowmobile engine emissions as percentages of revised 1970 national totals from all sources, snowmobiles appear to account for approximately 0.2 percent of hydrocarbons, 0.1 percent of CO, 0.004 percent of NO_x, 0.008 percent of particulate, and 0.0003 percent of SO_x. As percentages of revised 1970 mobile source emissions, snowmobiles are estimated to account for about 0.4 percent of hydrocarbons, 0.1 percent of CO, 0.009 percent of NO_x, 0.3 percent of particulate, and 0.009 percent of SO_x. All these figures are rather minimal on a national basis.

Since emissions from snowmobiles occur mainly in a few states and during a few months of the year, their local impact may be more severe in some cases than indicated by national comparisons. Particular instances may arise, for example, in which a number of machines are operated in a relatively small area; and this situation could lead to undesirable HC and CO levels. It should also be noted, however, that snowmobile emissions, being released primarily in suburban/rural areas and during leisure hours, should not be frequent contributors to air pollution episodes associated with highway vehicles or industrial processes. An estimate of seasonal and regional variation in snowmobile emissions shows that about 93% of such emissions occur in the northern region and 7% in the central region. About 63% of snowmobile emissions occur in the Dec.-Feb. quarter, and around 19% each in the late fall and early spring.

After a number of years of very rapid growth, the snowmobile market seems to be leveling off. This factor leads to a slowly increasing snowmobile population projected for the near future, with most sales as replacement rather than expansion of the population. It is not expected that drastic changes in snowmobile emissions will occur on a national basis due to any forseeable factor, but fuel shortages or rationing could change the whole picture.

LIST OF REFERENCES

1. "The Snowmobile Owner 1972," Snow Goer Trade magazine, August 1972, Webb Publishing Company, St. Paul, Minnesota.

2. Federal Register, Volume 38, No. 124, Part III, June 28, 1973; Section 85.074-10(a).

3. Altshuller, A. P., et al, Determination of Formaldehyde in Gas Mixtures by the Chromotropic Acid Method, Anal. Chem. 33:621, 1961.

4. Sawicki, E., et al, The 3-Methyl-3-benzathiazalone Hydrazone Test, Anal, Chem. 33:93, 1961.

5. Federal Register, Volume 37, No. 221, Part II, November 15, 1972; Section 85.874-13.

6. Federal Register, Volume 38, No. 124, Part III, June 28, 1973; Section 85.074-26(d).

7. Federal Register, Volume 37, No. 221, Part II, November 15, 1972; Section 85.774-18(i).

8. Hare, Charles T. and Springer, Karl J., "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Final Report Part 3,Motorcycles, Contract No. EHS 70-108, March 1973.

9. Hare, Charles T. and Springer, Karl J., "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Final Report Part 4,Small Air-Cooled Spark Ignition Utility Engines, Contract No. EHS 70-108, May 1973.

10. Hare, Charles T. and Springer, Karl J., "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," Final Report Part 1,Locomotive Diesel Engines and Marine Counterparts, Contract No. EHS 70-108, October 1972.

11. Hare, Charles T. and Springer, Karl J., "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines," (currently) Draft Final Report Part 5,Heavy-Duty Farm, Construction, and Industrial Engines, Contract No. EHS 70-108, July 1973.

12. Hare, Charles T. and Springer, Karl J., "Small Engine Emissions and Their Impact," SAE Paper No. 730859, Presented at the Society of Automotive Engineers Meeting in Milwaukee, Wisconsin, September 10-13, 1973.

13. Eccleston, B. H. and Hurn, R. W., "Exhaust Emissions from Small, Utility, Internal Combustion Engines," SAE Paper No. 720197, Presented at the Society of Automotive Engineers Congress in Detroit, Michigan, January 1972.

14. Donahue, J. A., et al, "Small Engine Exhaust Emissions and Air Quality in the United States," SAE Paper No. 720198, Presented at the Society of Automotive Engineers Congress in Detroit, Michigan, January 1972.

15. Optical Properties and Visual Effects of Smoke-Stack Plumes, A Cooperative Study: Edison Electric Institute and U.S. Public Health Service, Publication No. 999-AP-30, Cincinnati, Ohio, 1967.

16. Halow, John S. and Zeek, Susan J., "Predicting Ringelmann Number and Optical Characteristics of Plumes," Journal of the Air Pollution Control Association, Volume 23, No. 8, August 1973.

17. Letter from Mr. L. W. Foster of Polaris to C. T. Hare, March 16, 1973.

18. Letter from Mr. Joe Budd of John Deere to C. T. Hare, October 4, 1972.

19. Letter from Mr. J. H. Rose of Massey-Ferguson to John Nesbitt of ISIA, April 6, 1973, Submitted to C. T. Hare by Mr. Nesbitt.

20. Ward, Harry M., Griffith, Michael J., Miller, George E., and Stephenson, Donald K., "Outboard Marine Corp.'s Production Rotary Combustion Snowmobile Engine," SAE Paper No. 730119, Presented at the Society of Automotive Engineers Congress in Detroit, Michigan, January 8-12, 1973.

21. Letter from Mr. Harvey E. Schultz of Kohler Company to B. C. Dial of SwRI.

22. Letter and Enclosures from Mr. Martin A. Berk of John Deere to C. T. Hare, August 31, 1973.

23. Petroleum Products Survey No. 73, U.S. Department of the Interior, Bureau of Mines, January 1972.

24. Letter from Mr. John Nesbitt of ISIA to C. T. Hare, July 13, 1973.

25. The Off-Road Vehicle and Environmental Quality, Malcolm F. Baldwin, The Conservation Foundation, Washington, D.C., 1970.

26. Product News, May/June 1973 (Submitted by John Nesbitt of ISIA).

27. 1970 EPA Air Pollutant Inventory Estimates (Revised), 1973 Annual Report of the Council on Environmental Quality.

APPENDIX

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	—	1.71	15	138	102,000	8125	4.83	4.30	93	7.32	14.6	9.2
2	5500	2.20	2.81	17	309	116,400	2841	0.29	12.2	73.	39.8	46.9	1.9
3	5500	3.62	3.50	20	386	11370	1236	0.13	11.2	81.	48.3	48.3	2.9
4	5500	6.29	4.50	25	528	14100	1203	0.11	10.8	139.	95.1	101.	3.4
5	5500	14.5	12.3	23	828	34120	2104	6.53	7.21	158.	80.0	86.4	3.0
6	5500	21.5	15.	—	—	35600	1430	3.55	7.75	244.	349.	380.	4.3
7	5500	26.4	18.	—	—	46000	1924	6.26	5.75	195.	119.	129.	4.9
8	5500	27.6	20.	—	—	43600	2363	4.17	6.91	358.	305.	332.	5.1
9	2500	7.37	6.51	25	639	47650	3666	0.15	13.2	1060.	1577.	1686.	7.6
10	2500	6.72	7.42	24	574	66800	5412	6.71	5.71	80.	23.4	43.6	5.8
11	2500	5.64	4.39	22	587	43400	2434	0.59	9.38	326.	247.	292.	5.7
12	2500	3.76	3.24	21	508	35800	2169	0.11	8.17	76.	70.8	84.9	7.0
13	2500	1.95	2.20	22	354	33300	2221	0.19	8.88	34.	22.7	32.9	5.6
14	2500	0.95	1.94	23	251	46350	2710	1.80	8.09	28.	11.3	19.0	5.2
15	2500	—	1.73	24	168	78000	5496	4.04	5.33	39.	7.24	17.3	7.8
16	IDLE	—	1.59	22	130	97300	4090	4.55	4.27	48.	8.21	14.7	9.1
17	4000	14.2	9.78	15	867	38300	2772	2.51	7.33	636.	495.	518.	4.4
18	4000	13.0	9.00	15	828	36520	2445	3.37	7.21	395.	278.	315.	4.3
19	4000	10.6	8.67	17	750	34800	2634	4.76	6.79	147.	89.8	105.	3.6
20	4000	7.34	5.35	15	661	25000	1897	0.78	8.92	208.	133.	150.	3.5
21	4000	3.13	3.19	15	455	26400	1551	0.17	7.83	74.	37.0	46.3	6.5
22	4000	1.99	2.90	16	382	38400	2067	0.24	7.60	103.	53.3	53.7	6.9
23	4000	0.40	2.34	18	266	58000	3708	0.47	6.60	103.	28.0	44.8	8.6
24	7000	1.04	3.67	20	389	12300	1799	0.24	10.1	137.	98.3	105.	2.9
25	7000	4.15	5.51	22	575	17040	1462	0.15	9.74	447.	368.	370.	3.5
26	7000	8.42	9.11	20	699	29300	1935	3.55	8.06	231.	151.	168.	3.4
27	7000	16.2	15.	—	—	35200	2727	5.72	7.11	116.	72.2	80.1	4.1
28	7000	23.5	20.	—	—	32000	2654	3.06	8.81	277.	296.	302.	4.8
29	7000	24.9	26.	—	—	40000	4529	4.41	7.61	257.	203.	212.	5.1
30	7000	31.1	22.	—	—	30000	4225	2.06	8.73	928.	747.	783.	5.0
31	IDLE	—	1.32	25	223	92000	5634	4.90	4.74	86.	8.24	16.3	8.2

Engine ARCTIC CAT 440 Run 1 Date 3/73 Barometer 29.08

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F		FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
				Int.	Exh.								
1	IDLE	——	1.55	15	117	85650	11800	4.26	3.49	123	6.46	13	9.6
2	5500	1.96	3.16	15	328	13500	952	0.15	9.86	60	27.7	30.8	2.9
3	5500	3.62	3.43	18	413	13035	917	0.09	9.32	63	29.7	31.9	3.9
4	5500	7.51	5.97	23	645	16800	1171	0.21	10.5	158	135	169	3.2
5	5500	14.6	12.9	25	879	34200	2534	5.71	7.21	165	103	113	3.3
6	5500	21.1	16.	——	——	34400	2675	3.96	7.23	329	251	264	[illegible]
7	5500	25.7	18.	——	——	[illegible]	2939	4.07	6.84	388	351	441	[illegible]
8	5500	27.5	22	——	——	[illegible]	2386	2.04	8.12	1100	1098	1122	5.3
9	2500	7.67	6.51	25	632	46000	4528	0.10	7.86	1111	1042	1144	8.2
10	2500	6.67	7.91	25	554	60280	4016	6.43	4.30	59	21.6	[illegible]	[illegible]
11	2500	5.75	4.80	24	751	[illegible]	3733	1.25	8.88	226	165	177	[illegible]
12	2500	3.79	3.36	22	487	[illegible]	2994	0.11	8.99	122	74.4	[illegible]	[illegible]
13	2500	1.88	2.50	25	360	36000	3756	4.01	5.00	55	5.50	15.5	[illegible]
14	2500	.95	2.00	25	257	44000	2518	2.00	8.11	46	8.60	14.5	5.4
15	2500	——	1.76	24	174	[illegible]	3756	4.01	5.00	55	5.49	15.5	[illegible]
16	IDLE	——	1.53	23	137	[illegible]	9842	4.52	4.06	90	6.63	13.8	9.4
17	4000	14.5	11.7	27	902	37600	1858	1.21	9.17	1012	1175	1243	[illegible]
18	4000	13.4	10.3	25	808	40400	2699	4.46	7.69	240	172	182	4.2
19	4000	11.3	9.00	24	755	36600	2402	5.06	7.88	152	92.4	107	3.8
20	4000	7.58	6.00	25	657	26800	1668	2.33	7.84	152	90.4	101	3.3
21	4000	3.29	3.16	25	444	27000	1636	0.21	10.3	65	30.7	37.9	5.8
22	4000	1.45	2.86	25	381	35600	2082	0.25	9.34	79	44.6	51.0	6.6
23	4000	2.20	2.45	25	257	53150	3981	0.75	7.86	78	32.1	38.6	8.2
24	7000	1.05	3.43	25	415	14600	2103	0.10	11.9	98	28.4	31.9	3.4
25	7000	3.86	5.87	25	482	19900	1924	0.45	11.6	232	188.	195.	3.4
26	7000	8.49	8.18	23	618	30800	2883	3.89	8.86	146	101	106	3.4
27	7000	17.2	16.	——	——	40000	2666	5.39	6.23	87	88.	92	4.3
28	7000	24.9	18.	——	——	37200	2313	3.36	8.10	244	210.	255	4.9
29	7000	29.7	22.	——	——	46000	2484	4.10	7.38	144	170.	224	5.5
30	7000	30.9	22.	——	——	42000	2363	2.36	8.80	547	466.	484	5.7
31	IDLE	——	1.50	25	233	78800	5231	5.59	4.80	50	8.86	18.1	9.5

Engine ARCTIC CAT 440 Run 2 Date 3/73 Barometer 28.91

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	—	1.65	19	150	83500	10600	4.74	4.90	104	7.7	16	8.8
2	5500	2.78	3.21	15	365	12300	1084	0.09	14.37	80	29	35	2.9
3	5500	3.55	3.10	16	405	12600	891	0.04	13.96	61	37	37	3.3
4	5500	6.40	4.15	20	523	14900	931	0.04	13.85	102	69	74	3.3
5	5500	14.5	10.3	18	868	23600	1470	.3.02	9.11	320	289	297	3.4
6	5500	21.5	16.	—	—	32000	3170	3.00	9.39	540	420	434	4.1
7	5500	26.4	16.	—	—	39000	1870	3.85	7.40	492	367	376	4.7
8	5500	29.1	20.	—	—	37800	2032	1.52	8.77	1536	1267	1301	5.2
9	2500	7.14	6.00	25	586	42000	3813	0.21	9.07	805	788	907	6.8
10	2500	6.26	5.51	17	542	47600	2849	2.38	8.01	155	89	99	6.1
11	2500	5.46	4.95	17	561	40800	2911	0.28	9.73	278	281	286	5.9
12	2500	3.63	3.36	15	484	34800	2540	0.03	9 28	107	69	79	7.2
13	2500	1.88	2.12	16	361	33800	2065	0.07	10.05	58	23	33	6.2
14	2500	0.95	1.91	16	264	41000	2979	1.38	10.03	50	13	21	5.2
15	2500	—	1.82	18	180	63200	5743	3.80	6.18	72	7.4	16	7.8
16	IDLE	—	1.51	20	161	94400	10365	4.37	4.67	142	8.7	14	9.2
17	4000	13.7	9.47	15	944	38200	4728	1.43	10.43	935	730	757	4.4
18	4000	13.0	9.68	15	829	37000	2943	2.67	9.91	476	318	340	4.2
19	4000	11.1	8.47	15	753	36000	2758	4.39	9.08	186	101	115	3.6
20	4000	7.62	5.62	17	665	26000	2187	1.11	12.35	219	133	147	3.[illegible]
21	4000	3.29	2.86	19	454	22800	1789	0.13	12.23	116	60	71	4.2
22	4000	1.82	2.34	17	370	37600	2633	0.21	10.87	119	53	65	6.1
23	4000	0.20	2.17	16	269	52400	3536	0.36	8.77	127	53	58	8.1
24	7000	1.05	3 60	20	392	15400	1822	0.32	13.68	88	47	51	2.8
25	7000	4.21	5.81	18	638	21200	1547	0.69	13.64	262	217	226	3.1
26	7000	8.04	6.00	16	680	27600	2324	3.26	11.09	125	140	147	3.1
27	700	16.5	15.	—	—	37000	3190	5.30	6.53	61	72	82	4.3
28	7000	25.1	22.	—	—	37000	1634	3.77	6.86	274	189	207	4.1
29	7000	28.7	30.	—	—	48400	3398	5.67	5.52	125	82	88	5.[illegible]
30	7000	32.0	26.	—	—	38400	3079	2.42	7.50	668	577	6.0	4.1
31	IDLE	—	1.50	17	263	86400	8683	5.14	3.75	83	5.7	15	9.1

Engine ARCTIC CAT 440 Run 3 Date 3/13 Barometer 27.06

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1													
2	5500	1.96	3.03	23	448	10800	968	0.16	10.04	37.	24	29	~~2.6~~
3													
4													
5	5500	14.6	13.6	24	864	33400	2061	6.48	5.89	86.	71	77	3.4
6	5500	21.4	18.8	24	955	40400	2860	6.06	5.70	125	108	116	4.2
7	5500	25.4	23.0	28	975	46[illegible]	1738	6.37	5.35	131	96	106	4.6
8	5500	27.6	23.8	27	1021	45600	3424	4.03	6.46	397	325	343	5.1
9	2500	7.52	7.50	23	634	52000	3269	3.19	6.36	194	148	17	6.7
10													
11													
12	2500	3.91	4.14	15	479	38000	1541	0.12	9.26	134	75	89	7.2
13													
14													
15	2500	—	1.89	15	222	67200	5266	3.32	6.35	63	5.[illegible]	16	8.0
16	IDLE	—	1.65	15	142	83500	8214	4.27	4.54	70	5.7	13	9.7
17	4000	15.8	14.0	15	851	46000	2745	4.01	8.22	304	2[illegible]	244	4.4
18													
19													
20	4000	7.71	6.43	17	674	29000	2666	3.07	10.40	154	97	106	3.2
21													
22													
23	4000	—	2.14	17	307	53600	4692	0.36	8.16	115	43	65	8.7
24	7000	1.05	3.30	17	385	15900	1804	0.13	13.06	67	47	49	2.9
25													
26													
27	7000	15.4	16.4	24	892	42600	3192	6.46	7.22	109	63	69	4.2
28	7000	23.1	21.6	25	1006	45200	4664	5.36	7.78	148	93	110	4.7
29	7000	27.0	28.0	24	1035	55200	6306	6.95	5.32	111	54	67	5.1
30	7000	30.9	25.7	15	1060	44800	2333	3.78	6.77	360	264	298	5.4
31	IDLE	—	1.41	15	232	81600	9688	2.79	6.84	63	7.6	15	9.3

Engine ARCTIC CAT 440 Run 4 Date 3/73 Barometer 29.40

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1													
2	5500	1.96	2.98	15	339	10400	919	0.07	11.10	49	23	27	3.6
3													
4													
5	5500	14.2	11.5	15	851	30600	1971	5.43	7.78	155	101	111	3.3
6	5500	21.6	17.6	17	970	39600	3161	5.93	6.87	188	136	139	4.2
7	5500	25.4	21.2	17	965	45600	4696	5.94	6.56	202	137	149	4.9
8	5500	28.1	23.8	17	1012	47600	4938	4.20	7.54	392	339	356	5.1
9	2500	7.52	7.50	15	611	54800	7284	2.86	7.39	226	190	199	6.9
10													
11													
12	2500	3.76	3.50	15	502	33200	3633	0.05	8.98	100	78	88	7.0
13													
14													
15	2500	——	1.51	15	303	61600	6424	3.22	9.57	42	6.4	19	7.7
16	IDLE	——	1.46	15	161	80000	10068	4.43	4.48	63	7.3	17	9.7
17	4000	16.4	12.9	15	840	44800	8026	2.59	8.51	462	296	341	4.9
18													
19													
20	4000	7.62	6.79	18	690	29600	4216	3.99	8.93	116	86	98	3.2
21													
22													
23	4000	1.75	2.09	16	285	50400	3516	0.39	7.48	38	42	60	7.8
24	7000	——	3.75	22	331	14500	2368	0.09	10.89	37	34	38	3.4
25													
26													
27	7000	15.5	15.3	15	895	37600	2887	5.80	6.88	79	87	93	4.2
28	7000	24.9	22.0	14	990	44000	3713	5.30	6.53	157	135	144	4.5
29	7000	27.2	27.4	18	960	53600	4706	6.87	5.46	111	67	76	5.2
30	7000	29.5	25.7	22	1046	45200	3823	3.87	7.08	337	270	292	5.2
31	IDLE	——	1.50	19	416	83200	8617	5.37	4.20	63	9	17	8.6

Engine ARCTIC CAT 440 Run 5 Date 3/73 Barometer 28.89

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.25	12	181	69600	5491	4.44	5.45	108	[illegible]	17	12.1
2	4500	——	3.13	13	293	54400	2920	4.40	6.45	40	14	23	10.1
3	4500	4.46	4.34	14	598	16500	1425	3.02	10.38	123	57	65	6.3
4	4500	[illegible]	6.67	17	782	21400	1406	3.40	9.55	327	161	171	6.9
5	4500	[illegible]	11.2	17	849	37400	2018	4.71	7.91	479	269	313	8.4
6	4500	[illegible]	12.0	16	761	61200	2885	6.19	5.90	167	105	111	10.0
7	2500	1.66	2.73	10	285	46800	1990	4.19	6.38	20	18	26	9.1
8	2500	0.88	2.63	10	242	59600	3110	5.31	5.41	30	6.3	19	9.6
9	2500	——	1.95	10	175	78400	6349	5.07	4.15	82	7.3	18	12.1
10	5500	0.56	3.94	10	329	47200	5452	4.25	6.38	122	29	419	9.2
11	5500	6.12	6.05	11	662	19000	2301	2.88	9.03	195	101	107	6.2
12	5500	11.9	9.82	14	791	26600	1698	4.26	9.61	309	173	190	6.5
13	5500	18.6	14.4	10	692	36600	2879	3.18	7.95	688	345	413	6.5
14	5500	21.5	18.0	15	893	46400	3417	3.20	7.53	773	346	419	7.3
15	5500	22.9	22.5	16	823	57600	4197	5.95	5.51	217	104	110	7.6
16	IDLE	——	1.25	17	326	74400	9117	4.69	5.04	130	7.3	8.2	9.3
17	7000	23.5	24.0	22	899	50800	10008	6.47	6.02	237	74	111	6.8
18	7000	21.3	18.0	20	488	40400	2838	4.00	8.57	430	171	160	5.9
19	7000	18.4	15.7	16	990	38200	2834	3.90	8.76	359	150	153	5.7
20	3500	——	2.54	16	432	62400	5438	5.04	5.83	112	11	24	8.1
21	3500	1.75	3.21	15	392	37400	4085	3.43	8.71	65	22	31	5.5
22	3500	3.00	3.53	14	505	20000	2623	2.23	10.88	99	43	48	4.1
23	3500	6.66	4.74	15	673	21600	2130	1.62	10.94	325	164	183	4.4
24	3500	9.74	6.43	16	764	26400	1994	1.53	10.53	1255	693	702	4.9
25	3500	12.1	14.4	25	734	56000	4255	6.56	5.54	173	88	910	5.5
26	6500	25.1	24.0	26	904	52000	5460	6.30	6.32	215	76	99	6.2
27	6500	23.1	17.1	26	1024	23200	4921	2.98	9.11	901	449	453	5.8
28	6500	19.4	15.7	25	940	33800	2820	4.19	8.92	357	163	180	5.1
29	6500	13.3	12.0	24	942	28600	2611	4.44	9.08	322	131	151	4.5
30	6500	1.98	3.60	22	334	18000	1165	5.27	9.66	923	29	379	3.4
31	IDLE	——	1.27	19	152	76000	5751	4.34	5.46	113	6.36	15	9.5

Engine POLARIS 335 Run 1 Date 4/73 Barometer 29.41

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	—	0.97	12	345	65600	7517	2.71	4.37	—	5.7	11.6	11.2
2	4500	0.66	3.20	12	384	49200	5940	2.53	6.33	—	16	24	8.5
3	4500	4.61	4.74	12	726	22800	3059	1.26	9.36	—	72	83	4.9
4	4500	9.68	7.30	12	850	28200	2484	3.17	8.29	—	121	146	4.6
5	4500	14.8	11.6	13	905	41600	3597	4.16	7.06	—	228	246	5.5
6	4500	18.2	18.2	13	817	61600	5686	5.76	5.11	—	109	127	7.0
7	2500	1.63	2.59	13	482	40800	4012	2.15	7.94	—	34	45	6.8
8	2500	0.88	2.18	13	391	54400	5895	3.92	5.76	—	10	22	8.1
9	2500	0.13	1.86	12	320	66000	7819	3.91	4.50	—	6.5	19	9.8
10	5500	0.81	3.79	14	435	42400	5869	2.66	7.41	—	39	54	7.0
11	5500	5.51	6.00	17	758	18600	4839	2.11	9.57	—	87	107	4.3
12	5500	11.7	9.00	12	875	23600	1784	2.81	6.23	—	131	147	5.2
13	5500	16.8	13.1	12	948	34800	2494	3.48	5.85	—	224	251	5.2
14	5500	19.8	15.9	12	962	44000	3608	3.74	5.34	—	338	362	5.9
15	5500	22.4	21.6	15	899	58000	5131	5.95	4.18	—	102	125	6.8
16	IDLE	—	1.18	12	478	75200	9869	3.68	4.09	—	9.7	20	9.3
17	7000	27.7	21.7	16	1110	39600	6620	3.51	6.34	—	318	364	6.1
18	7000	24.5	19.2	21	1113	32000	4855	1.95	7.38	—	484	622	5.3
19	7000	20.0	15.9	15	1012	35600	3908	3.82	6.86	—	186	248	5.0
20	3500	0.18	2.63	11	418	64800	3721	3.68	4.21	—	15	23	8.7
21	3500	1.12	3.10	11	403	55200	5726	2.76	5.27	—	21	27	7.9
22	3500	1.96	3.19	11	478	40400	5115	1.90	6.44	—	35	43	6.5
23	3500	3.96	3.91	11	677	32000	4527	0.66	7.38	—	81	94	6.1
24	3500	5.61	4.93	12	746	34000	3655	0.93	7.44	—	132	151	6.0
25	3500	11.2	14.5	13	757	64800	5466	6.22	4.10	—	62	87	7.5
26	6500	20.2	20.9	17	1002	46000	6626	4.02	5.75	—	273	273	6.3
27	6500	2[illegible].8	16.5	19	1010	35200	5509	3.17	6.44	—	455	465	6.1
28	6500	17.6	14.8	17	1018	33600	4421	3.69	6.70	—	407	434	5.2
29	6500	12.9	11.3	20	947	[illegible]	3454	4.95	6.56	—	[illegible]	143	4.2
30	6500	1.30	3.58	25	592	[illegible]	2860	4.47	7.36	—	47	60	3.8
31	IDLE	—	1.15	18	367	[illegible]	6562	3.56	4.71	—	9.2	18	8.9

Engine POLARIS 335 Run 4 Date 5/73 Barometer 29.12

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.15	11	158	74000	6317	2.81	4.55	——	[illegible]	13	9.7
2	4500	0.67	3.31	11	354	54400	7221	2.87	5.74	——	20	29	7.2
3	4500	4.51	4.66	11	716	25200	5158	1.57	8.07	——	76	94	4.4
4	4500	9.59	7.50	12	870	30000	3555	3.39	7.11	——	144	170	4.3
5	4500	14.5	11.5	12	894	42400	3778	3.95	6.25	——	308	335	5.4
6	4500	17.6	17.8	15	822	62800	5226	6.07	4.41	——	102	117	6.8
7	2500	1.50	2.40	13	531	50400	5462	4.44	6.01	——	28	42	6.1
8	2500	0.61	2.24	13	390	66000	6970	4.57	5.04	——	10	25	7.4
9	2500	0.25	1.85	14	313	79600	8654	2.81	6.39	——	8	20	8.8
10	5500	1.33	3.87	15	463	48000	7263	2.76	5.27	——	41	54	6.7
11	5500	5.51	6.92	14	746	20800	5551	2.16	8.90	——	99	107	3.8
12	5500	10.8	9.56	11	920	28000	1582	3.49	6.88	——	129	140	4.4
13	5500	16.7	12.7	11	994	41200	2535	2.88	6.61	——	383	406	5.5
14	5500	19.8	18.0	12	941	62800	3656	4.02	5.61	——	264	291	6.7
15	5500	21.6	22.0	12	875	64400	3586	5.70	3.95	——	107	119	7.3
16	IDLE	——	1.14	11	442	100800	8589	3.41	3.74	——	9	18	9.9
17	7000	27.3	24.7	13	1011	42700	2595	4.99	5.69	——	20	24	6.5
18	7000	26.7	16.8	11	1117	31600	2152	2.51	5.55	——	296	305	6.2
19	7000	19.2	15.7	11	1014	32800	3147	3.72	5.90	——	112	121	5.1
20	3500	0.35	2.61	20	469	89600	3189	4.52	3.77	——	9	13	8.6
21	3500	1.09	3.10	13	411	91200	9741	4.48	4.61	——	9	11	7.3
22	3500	1.99	3.56	11	472	46000	8173	3.73	5.63	——	19	26	5.9
23	3500	5.26	4.91	18	674	32600	7527	1.88	7.71	——	51	66	5.1
24	3500	7.72	6.79	15	754	40000	5610	3.22	6.81	——	84	89	5.3
25	3500	10.5	15.0	16	740	80800	9577	7.14	3.61	——	26	34	6.8
26	6500	24.4	20.7	18	1020	56000	6907	4.77	5.75	——	113	125	6.2
27	6500	21.2	16.6	11	1043	36400	4073	1.62	6.92	——	387	479	6.5
28	6500	16.9	13.8	11	925	34400	3987	5.45	5.19	——	111	120	4.9
29	6500	12.6	11.8	13	938	31200	3605	5.69	5.32	——	99	115	3.9
30	6500	1.63	4.32	28	571	32000	3371	4.43	5.73	——	53	59	3.9
31	IDLE	——	1.09	13	325	94400	9307	3.59	4.10	——	——	17	9.2

Engine POLARIS 335 Run 5 Date 5/73 Barometer 29.19

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.18	11	115	99200	7649	2.68	5.27	——	4.86	12	10.2
2	4500	0.67	2.44	11	384	56000	6799	2.97	6.69	——	17	26	9.3
3	4500	4.33	5.08	11	712	25600	3451	2.35	9.27	——	66	77	3.1
4	4500	9.22	7.50	11	857	31200	3131	3.53	8.30	——	128	142	4.1
5	4500	14.1	11.5	14	874	46000	4749	4.37	7.13	——	179	196	[illegible]
6	4500	17.7	18.9	17	795	76400	5642	6.91	4.81	——	54	71	6.6
7	2500	1.51	2.25	20	527	54400	7631	3.98	6.85	——	22	31	5.9
8	2500	0.84	2.43	24	378	45200	9077	4.43	5.73	——	9	22	7.0
9	2500	0.12	2.24	11	255	109,600	7469	4.32	3.49	——	7.4	18	10.1
10	5500	1.10	3.37	11	970	48400	7995	2.90	5.95	——	35	47	6.8
11	5500	5.14	6.49	11	730	24200	5202	4.01	6.92	——	75	93	4.0
12	5500	11.9	9.82	11	908	30800	3580	5.00	6.62	——	111	134	3.9
13	5500	16.4	13.7	11	963	43600	4326	4.36	6.15	——	161	198	5.3
14	5500	19.3	17.3	12	920	54900	6006	4.16	5.95	——	209	222	6.4
15	5500	20.8	21.8	16	883	70800	3218	6.11	4.90	——	86	109	6.7
16	IDLE	——	0.82	14	519	102,400	17467	3.28	4.78	——	8.8	16	9.6
17	7000	26.3	23.3	19	984	53600	8466	6.09	5.22	——	103	116	5.9
18	7000	24.9	24.1	19	1002	53600	6702	5.49	5.53	——	112	126	5.8
19	7000	18.4	16.1	11	1029	35800	1983	3.28	7.61	——	198	225	5.3
20	3500	0.36	2.67	12	523	82400	6189	4.70	4.66	——	16	27	8.4
21	3500	0.53	3.05	11	409	84840	9147	4.58	4.78		9.1	21	7.9
22	3500	2.71	3.79	11	486	35200	8494	3.33	7.69	——	36	47	5.4
23	3500	5.27	5.05	11	657	34200	5572	2.56	8.16	——	70	50	5.1
24	3500	7.89	6.61	11	748	44800	5466	2.95	7.39	——	117	132	5.5
25	3500	10.9	10.3	17	744	76800	8447	7.17	4.42	——	40	50	6.9
26	6500	24.6	23.4	22	941	55200	10128	5.14	6.18	——	130	161	6.1
27	6500	22.4	17.4	23	1026	41200	8044	3.28	7.70	——	315	355	5.7
28	6500	19.3	15.3	23	986	38800	5498	4.58	7.42	——	156	176	4.8
29	6500	12.7	11.0	25	925	24400	4609	4.12	8.21	——	118	153	4.2
30	6500	1.31	3.55	26	657	27200	3352	4.11	8.38	——	46	55	4.2
31	IDLE	——	1.15	16	120	——	11142	3.36	4.90	——	6.2	11	10.3

Engine POLARIS 335 Run 6 Date 5/73 Barometer 29.14

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.02	11	156	96000	5901	3.09	4.11	——	5.83	12	10.4
2	4500	0.68	3.35	11	333	58000	3072	3.41	6.72	——	21	30	9.6
3	4500	4.33	4.84	11	696	24400	3730	1.60	9.91	——	74	87	4.1
4	4500	9.02	7.71	11	857	30400	2818	2.62	8.87	——	164	178	4.4
5	4500	14.1	11.7	11	913	41200	3819	3.01	7.96	——	377	400	5.7
6	4500	17.6	16.6	11	963	64800	5843	4.14	6.30	——	415	438	6.9
7	2500	1.53	2.28	12	566	51200	6694	4.11	7.06	——	28	444	6.2
8	2500	0.65	1.97	14	358	80000	9629	7.83	5.34	——	10	23	7.4
9	2500	0.13	2.09	14	292	100,800	13709	8.24	4.50	——	9	21	8.6
10	5500	0.81	3.75	12	457	50800	11047	5.40	6.97	——	37	50	6.5
11	5500	5.73	9.86	11	765	21400	5566	3.12	9.86	——	84	104	3.7
12	5500	12.0	13.5	11	933	22800	3709	2.80	9.22	——	129	151	3.9
13	5500	16.3	14.8	11	962	40000	5231	3.03	7.39	——	258	344	5.5
14	5500	18.7	18.6	14	990	48000	6526	1.70	7.23	——	615	643	6.8
15	5500	21.1	20.0	12	936	60000	7649	4.76	5.84	——	514	546	7.0
16	IDLE	——	1.03	13	152	101,600	11949	3.14	4.99	——	6.9	16	9.6
17	7000	27.0	26.0	12	973	58400	4254	6.41	5.75	——	200	218	5.5
18	7000	23.4	19.8	15	1079	36400	5559	2.98	7.96	——	387	414	5.5
19	7000	20.8	16.0	16	1035	33600	3439	3.77	8.06	——	240	249	9.5
20	3500	0.36	2.88	13	527	82400	6006	4.67	5.44	——	17	28	7.5
21	3500	1.32	3.03	13	453	52600	7640	3.87	6.85	——	22	31	6.2
22	3500	2.[illegible]3	3.79	17	533	38000	5516	3.44	8.27	——	38	48	4.7
23	3500	5.23	4.62	15	675	32000	4560	2.12	9.29	——	81	93	4.7
.24	3500	8.07	6.49	12	620	38800	4797	2.25	8.18	——	149	163	5.9
25	3500	11.0	14.8	14	743	76400	8044	6.04	4.91	——	.63	79	6.9
26	6500	25.7	21.9	12	973	48,100	8494	3.91	7.07	——	45	485	5.9
27	6500	22.5	16.5	13	1041	36000	5817	2.80	8.14	——	481	521	5.3
28	6500	19.3	18.8	15	1009	36000	3646	4.03	7.71	——	200	232	4.6
29	6500	13.0	11.3	19	971	27600	3630	3.92	8.32	——	155	163	3.8
30	6500	0.99	3.91	17	686	28000	2943	4.96	7.56	——	51	55	3.7
31	IDLE	——	1.09	13	426	99400	15584	3.28	4.91	——	7.7	17	8.9

Engine POLARIS 335 Run 7 Date 5/73 Barometer 29.52

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	0.78	12	99	72000	6836	1.61	7.48	70	5.3	13	8.4
2	4000	——	2.14	12	197	60800	7062	0.47	7.81	77	8.1	16	9.5
3	4000	0.62	3.00	12	259	56000	3856	4.23	7.70	74	15	23	5.8
4	4000	1.56	3.60	12	296	48800	4211	2.04	9.10	87	29	30	5.7
5	4000	3.36	4.19	15	396	47600	4631	2.18	7.69	95	33	45	6.7
6	4000	5.61	5.57	12	492	49600	3689	0.47	8.23	182	152	170	7.5
7	4000	6.37	5.90	12	523	52800	3994	0.42	8.06	323	276	299	[illegible]
8	4000	7.43	7.15	13	553	53600	4843	0.08	7.42	464	312	358	[illegible]
9	3000	2.65	3.07	12	360	51200	4887	0.64	8.05	70	57	81	[illegible]
10	3000	1.66	2.83	12	297	85200	7220	6.12	5.10	24	8.1	29	[illegible]
11	[illegible]	0.56	1.78	12	224	55200	4796	0.70	7.70	18	8.3	20	8.1
12	[illegible]	0.27	1.50	12	180	59200	4183	0.63	7.22	0	5.6	14	[illegible]
13	[illegible]	——	1.56	12	161	62800	5382	0.68	6.82	0	5.0	14	[illegible]
14	[illegible]		2.03	12	189	18500	1300	0.55	11.1	0	35	41	2.9
15	[illegible]	[illegible]	4.93	12	530	45600	4088	3.20	6.98	75	57	[illegible]	4.0
16	IDLE	——	0.96	12	131	64000	5428	0.33	6.39	32	3.6	10	11.2
17	6500	[illegible]	8.82	15	715	40600	2655	0.38	8.07	189	161	[illegible]	7.8
18	6500	12.4	11.7	22	[illegible]	46400	2056	0.57	8.31	496	399	450	7.0
19	[illegible]	14.	12.5	[illegible]	820	47600	2863	0.78	7.13	657	547	[illegible]	7.0
20	[illegible]	15.8	13.3	[illegible]	[illegible]	48000	4945	0.33	7.08	643	577	614	[illegible]
21	[illegible]	10.6	9.40	[illegible]	652	[illegible]	4187	0.65	7.14	607	510	571	7.6
22	[illegible]	9.42	7.76	20	655	49200	3921	0.77	7.71	467	401	443	7.0
23	5000	[illegible]	6.99	22	640	46100	3073	0.65	7.62	317	268	318	7.1
24	5000	[illegible]	5.76	22	[illegible]	40200	3143	0.19	7.84	177	138	176	7.1
25	5000	2.51	3.64	24	414	39200	3090	1.54	8.07	69	49	71	5.6
26	5000	——	2.90	12	240	48800	3986	0.45	8.32	70	49	72	5.7
27	2500	——	1.30	11	171	63600	6352	0.27	6.54	45	5.0	12	10.5
28	2500	0.26	1.43	12	153	60000	6044	0.32	6.86	38	5.2	11	10.1
29	2500	0.65	1.76	11	185	53000	6139	0.24	7.66	44	7.3	16	9.2
30	2500	1.28	2.02	11	222	48000	5221	0.19	8.34	51	14	23	8.0
31	IDLE	——	1.07	12	130	67000	8241	0.26	6.76	44	53	14	9.9

Engine ROTAX 248 Run 2 Date 7/73 Barometer 29.28

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2, %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2, %
1	IDLE	—	0.97	10	143	66800	6059	0.22	4.35	51	3.5	8.6	11.4
2	4000	—	2.26	10	208	56400	5025	0.51	5.38	46	6.7	11.4	9.5
3	4000	0.96	2.67	11	261	50800	4592	0.34	6.24	54	14	23	7.8
4	4000	1.52	2.82	10	276	46800	4366	0.38	7.16	74	29	41	6.8
5	4000	3.41	4.43	10	402	51600	4284	1.95	5.51	44	17	23	8.8
6	4000	5.15	4.91	11	475	[illegible]	4827	0.65	7.14	152	105	124	8.1
7	4000	6.78	6.00	11	528	54800	4930	0.55	6.64	247	186	223	9.0
8	4000	6.75	7.30	12	554	55600	5176	0.08	7.10	527	434	450	9.1
9	3000	2.72	2.97	12	367	50400	4859	0.50	6.60	71	71	103	7.3
10	3000	1.80	2.38	11	291	48800	4759	0.36	6.77	32	34	56	7.0
11	3000	0.75	1.88	10	218	[illegible]	5013	0.36	7.82	19	9	24	8.2
12	3000	0.28	1.64	10	188	59200	5154	0.36	7.24	20	5.9	19	9.0
13	3000	—	1.63	10	171	60800	5630	0.43	7.08	25	5.2	16	9.5
14	6500	—	2.27	11	201	20300	2518	0.12	11.8	49	33	43	4.3
15	6500	3.78	6.73	11	588	41800	3547	0.31	8.51	115	85	92	8.2
16	IDLE	—	1.03	12	201	69600	5770	0.29	6.92	32	4.2	15	10.3
17	6500	9.77	9.00	13	716	44000	2641	0.28	8.70	229	151	172	8.1
18	6500	13.0	13.4	10	808	45600	3685	0.33	8.56	374	239	303	7.9
19	6500	15.0	12.9	12	840	46400	4160	0.26	8.16	506	364	429	8.2
20	6500	16.5	13.0	15	847	45200	4151	0.29	8.33	505	368	444	8.0
21	5000	10.3	9.00	14	689	54400	6642	0.72	8.84	485	392	497	7.5
22	5000	9.81	8.18	13	671	49600	5756	0.79	8.93	400	391	496	7.5
23	5000	8.31	7.27	11	658	46400	5266	0.66	9.02	277	196	237	7.1
24	5000	5.26	5.33	12	584	40800	4474	0.22	8.97	148	84	112	7.7
25	5000	2.76	4.36	10	453	42400	4596	2.51	2.08	81	34	53	6.5
26	5000	—	2.29	12	305	51600	5110	0.65	7.80	57	11	26	8.4
27	2500	—	1.00	13	207	63200	9944	0.36	6.69	50	5.1	14	10.2
28	2500	0.26	1.44	11	176	58400	8125	0.38	6.76	53	5.3	13	9.6
29	2500	0.65	1.61	10	208	54800	7852	0.31	7.65	103	7.5	14	9.3
30	2500	1.45	2.02	10	296	50100	7768	0.24	8.78	95	21	36	8.8
31	IDLE	—	1.00	11	197	64000	12078	0.29	6.78	71	5.3	14	10.3

Engine ROTAX 248 Run 3 Date 7/73 Barometer 29.34

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.01	11	172	66800	5660	0.32	6.62	39	4.5	9.4	10.4
2	4000	——	2.08	10	211	56000	4743	0.41	7.08	38	6.1	12	9.2
3	4000	1.17	2.79	10	266	47600	4238	0.26	8.25	50	16	26	7.3
4	4000	1.60	2.65	11	316	44000	4315	0.28	8.51	57	26	39	7.4
5	4000	3.29	4.50	10	424	47600	4499	0.26	8.33	83	46	64	7.9
6	4000	5.60	4.78	11	496	50000	4672	0.72	8.21	209	149	183	6.9
7	4000	6.21	5.90	12	542	52800	4489	0.85	8.04	322	262	294	7.5
8	4000	7.54	7.30	14	582	56000	5330	0.75	7.81	428	451	488	7.9
9	3000	2.83	3.65	12	453	55200	4338	1.31	6.94	52	29	57	9.1
10	3000	1.63	2.73	10	324	60000	5145	5.47	6.52	43	12	34	5.6
11	3000	0.81	1.85	11	269	52800	5267	0.27	7.24	39	7.9	20	9.0
12	3000	0.27	1.75	12	222	48800	4833	0.33	7.32	33	6.5	15	8.6
13	3000	——	1.45	11	191	61600	4759	0.41	6.77	32	5.0	14	9.3
14	6500	——	2.23	10	205	20800	2154	0.32	11.1	65	43	55	3.1
15	6500	3.88	3.93	10	327	28800	2479	1.70	9.49	127	102	120	3.9
16	IDLE	——	1.03	12	194	64800	5642	0.38	6.84	41	4.7	13	7.6
17	6500	8.86	9.57	12	744	39200	1784	0.49	8.54	215	183	211	7.2
18	6500	12.7	11.7	21	760	44000	2677	0.64	8.66	357	484	530	6.4
19	6500	14.3	13.2	22	811	45600	3043	0.79	8.47	606	548	585	6.9
20	6500	16.6	13.3	26	830	48000	3283	0.52	8.49	717	623	714	7.0
21	5000	10.5	10.0	10	697	52400	4178	0.38	7.65	524	370	444	8.5
22	5000	9.67	9.47	11	695	52400	3709	0.47	7.72	492	383	444	7.9
23	5000	7.37	7.42	12	677	46400	3973	0.54	8.48	278	220	270	7.6
24	5000	5.41	4.24	11	600	40800	3301	0.25	8.34	136	83	115	8.0
25	5000	2.95	4.21	10	396	40200	3584	1.60	8.15	31	44	57	6.9
26	5000	——	2.40	10	302	52400	4427	0.63	7.63	52	19	32	8.1
27	2500	——	1.14	11	206	63200	6668	0.37	6.39	36	11	17	9.8
28	2500	0.50	1.48	10	189	52000	6802	0.24	6.39	25	6.0	15	9.9
29	2500	0.59	1.52	10	202	53200	5901	0.22	7.00	254	7.1	18	9.3
30	2500	1.42	1.98	10	243	46400	4708	0.19	8.00	48	20	37	7.8
31	IDLE	——	0.88	——	——	64800	7510	0.38	6.76	25	6.2	16	9.6

Engine ROTAX 248 Run 4 Date 7/73 Barometer 29.31

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	1.00	10	158	67600	5696	0.32	5.95	48	3.9	9.2	10.6
2	4000	——	2.05	10	205	54400	4764	0.55	6.45	52	6.2	12	9.5
3	4000	0.96	2.38	10	261	48000	4266	0.50	7.40	64	13	20	8.2
4	4000	1.60	2.39	10	296	44400	4338	0.38	7.81	76	21	37	7.4
5	4000	3.49	4.43	10	415	49600	4499	2.24	6.42	78	21	48	7.7
6	4000	5.41	5.14	10	510	48400	4708	0.83	7.37	189	128	174	7.4
7	4000	6.49	6.15	10	554	51200	4528	0.75	7.21	296	222	269	8.0
8	4000	7.60	7.61	11	594	56800	5382	0.27	7.24	584	516	577	8.1
9	3000	2.65	2.83	10	433	48400	4343	0.24	7.92	57	72	02	7.4
10	3000	[illegible]	2.75	11	345	50000	5324	0.83	7.78	89	35	55	6.2
11	3000	0.97	1.96	11	275	54400	5284	0.32	6.86	58	9.3	23	8.7
12	3000	0.38	1.49	11	227	55600	4874	0.33	6.46	60	[illegible]	16	9.2
13	3000	——	1.63	11	191	58400	4789	0.41	6.09	41	[illegible]	13	9.7
14	6500	——	2.13	10	201	18400	2183	0.13	10.0	62	[illegible]	47	3.3
15	6500	4.66	6.49	11	488	37600	2571	0.45	7.64	177	[illegible]	134	7.9
16	IDLE	——	1.07	12	240	63600	5684	0.34	6.09	45	[illegible]	13	9.7
17	6500	8.02	9.78	11	727	40800	1804	0.41	7.64	204	166	193	7.7
18	6500	13.2	11.2	11	817	44400	2703	0.65	7.80	375	[illegible]	[illegible]	7.0
19	6500	14.3	12.0	16	937	48000	3076	0.70	7.46	523	471	490	7.2
20	6500	15.9	13.2	19	868	47200	3330	0.29	7.41	558	530	576	7.9
21	5000	10.8	9.84	11	669	52800	4228	0.11	6.71	483	394	454	8.1
22	5000	8.99	7.69	12	668	49600	3709	0.67	7.55	376	296	347	7.2
23	5000	7.77	6.61	5	651	44800	3999	0.63	7.80	309	221	272	7.0
24	5000	5.62	5.90	10	559	40800	3340	0.22	7.17	180	94	125	7.9
25	5000	3.04	4.11	10	459	41600	3678	0.15	7.01	80	43	60	6.8
26	5000	——	2.22	10	321	52000	4480	0.50	6.52	45	23	33	8.9
27	2500	——	1.07	11	216	65200	6718	0.34	5.59	24	5.0	14	10.7
28	2500	0.28	1.46	11	176	62000	6846	0.34	6.16	29	5.9	14	9.6
29	2500	0.55	1.56	11	194	55600	5933	0.37	6.31	14	5.5	14	9.6
30	2500	1.45	1.41	10	241	46800	4718	0.38	7.65	51	21	28	7.7
31	IDLE	——	1.04	——	——	66800	7566	0.29	6.25	15	6.0	14	10.1

Engine ROTAX 248 Run 5 Date 7/73 Barometer 29.28

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	2.71	10	294	44000	2086	6.47	6.39	79	10	22	3.2
2	3500	——	5.05	24	554	5500	327	4.70	9.52	90	50	59	0.4
3	3500	3.09	6.49	20	651	3525	269	4.35	10.05	114	92	101	0.4
4	3500	5.26	7.83	20	634	5800	287	6.43	5.[illegible]5	124	83	87	0.5
5	3500	11.6	10.3	24	849	4275	75	4.97	6.48	265	246	255	0.4
6	3500	17.5	12.9	26	990	4125	85	5.21	6.54	474	428	428	0.4
7	3500	23.0	15.7	25	1002	4500	176	4.82	7.10	655	614	614	0.5
8	2500	7.52	7.50	26	67	5950	195	6.78	6.44	103	105	105	0.4
9	2500	3.63	4.70	27	531	5750	239	5.69	7.27	79	74	83	0.4
10	2500	——	3.96	29	454	20800	720	7.44	6.40	42	24	35	1.2
11	6000	0.60	9.89	12	932	1650	134	3.31	7.18	149	120	127	0.2
12	6000	——	15.7	——	——	2650	1.02	5.95	7.74	225	202	202	0.2
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													

Engine OMC ROTARY Run 1 Date 6/73 Barometer ________

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	——	3.29	17	332	47600	2776	8.17	6.42	76	10	23	3.2
2	3500	0.88	5.71	21	547	13200	611	7.48	8.11	45	44	53	1.0
3	3500	2.81	6.96	24	620	12000	468	7.33	8.90	104	54	59	1.0
4	3500	5.96	7.50	15	670	6250	616	5.41	9.73	194	124	124	0.7
5	3500	11.6	10.4	13	828	5320	189	7.74	8.25	254	153	153	0.6
6	3500	17.9	13.5	15	964	5150	158	6.10	9.65	370	323	323	0.6
7	3500	23.7	15.3	17	1026	5200	233	9.08	11.09	1040	932	496	0.6
8	2500	7.67	6.18	17	694	4250	122	1.59	12.27	[illegible]	431	431	1.1
9	2500	3.96	4.83	24	565	5600	181	3.74	10.91	[illegible]	110	116	0.7
10	2500	0.50	3.53	20	465	11200	299	6.52	8.97	45	39	46	0.9
11	6000	1.50	10.0	24	1041	338	——	0.04	12.04	[illegible]	185	187	3.3
12	6000	9.32	15.0	16	1300	375	105	0.05	11.32	[illegible]	137	143	3.8
13	6000	19.0	16.9	19	1136	3350	1490	3.62	10.74	[illegible]	278	236	[illegible]
14	6000	28.6	23.2	16	1218	3550	267	6.00	9.13	[illegible]	[illegible]	271	0.3
15	6000	32.4	24.0	17	1176	4150	297	6.30	9.10	363	296	296	0.4
16													
17	6000	33.1	27.2	25	950	6000	22.5	6.77	8.78	318	248	248	0.9
18	4000	27.3	20.6	25	1036	7300	1600	7.83	8.26	254	142	192	0.7
19	4000	24.1	17.6	15	1004	5800	2834	5.94	9.03	449	340	340	[illegible]
20	4000	20.9	15.7	25	1006	5700	412	5.45	9.36	409	362	362	[illegible]
21	4000	7.01	7.54	24	811	4900	1264	3.47	10.85	248	179	185	0.5
22	4000	3.61	6.67	23	724	5000	350	4.99	9.69	145	102	104	0.6
23	4000	0.59	5.93	24	661	6500	336	6.54	8.72	45	63	69	0.6
24	5000	0.75	7.61	20	774	2650	258	3.34	10.76	146	113	124	0.4
25	5000	4.22	10.0	22	889	3050	236	4.24	10.06	238	207	211	0.4
26	5000	7.92	10.9	23	920	3550	1441	3.53	10.53	324	283	283	0.5
27	5000	15.5	13.6	13	1016	3500	149	3.42	12.31	350	320	323	0.4
28	5000	23.5	18.0	14	1121	4475	1032	5.02	10.38	440	347	347	0.4
29	5000	28.1	21.2	15	1152	4725	1332	6.38	9.95	337	272	276	0.5
30	5000	31.3	24.8	18	1152	5350	1436	7.23	9.29	294	220	220	0.5
31													

Engine OMC ROTARY   Run 2   Date 6/73   Barometer 29.18

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1													
2	3500	0.35	5.32	12	410	12600	3710	7.11	8.58				
3	3500	2.81	6.34	15	585	8600	1066	7.27	8.65				
4	3500	6.23	7.09	17	659	5950	487	4.90	10.50				
5	3500	11.9	10.2	16	863	4750	348	3.34	11.61				
6	3500	18.3	13.1	19	964	5850	347	5.47	10.14				
7	3500	22.8	17.1	21	1003	7400	380	7.63	8.54				
8	2500	7.52	6.92	23	668	7650	393	7.35	8.83				
9	2500	3.76	5.43	22	532	8950	417	7.75	8.53				
10	2500	0.25	4.44	21	474	29400	914	9.17	6.58				
11	6000	1.20	9.23	24	837	3650	277	2.54	12.89				
12	6000	9.84	12.7	13	1004	1920	343	2.33	10.87				
13	6000	19.2	18.5	18	1120	2920	745	4.10	10.79				
14	6000	28.0	22.5	20	1121	3620	791	5.70	9.62				
15	6000	31.9	26.7	20	1161	3950	772	5.97	9.70				
16													
17	6000	34.0	28.2	24	1197	5000	1245	6.75	[illegible].15				
18	4000	27.7	20.9	22	1034	7650	770	7.65	8.56				
19	4000	25.1	18.0	21	1041	5400	843	5.54	9.93				
20	4000	20.8	15.0	21	1024	5100	708	5.02	10.38				
21	4000	7.22	7.70	20	826	3400	293	2.80	11.92				
22	4000	3.17	6.55	20	692	5900	109	5.97	9.70				
23	4000	0.59	5.43	19	628	6500	72	6.43	9.27				
24	5000	0.75	7.30	20	785	2190	27	2.63	12.11				
25	5000	4.01	10.3	22	821	2680	439	2.38	11.85				
26	5000	8.43	11.1	25	919	2680	35	2.97	11.67				
27	5000	16.7	14.1	25	983	3800	325	4.56	10.33				
28	5000	24.0	18.0	25	1072	4100	244	5.15	10.17				
29	5000	27.1	23.2	22	1125	4350	589	4.93	9.89				
30	5000	33.1	25.7	25	1175	4620	447	6.45	8.99				
31													

Engine OMC ROTARY   Run 3   Date 6/73   Barometer 29.13

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1													
2	3500	0.18	5.33	14	518	10400	1202	7.14	8.15	85	42	46.8	0.7
3	3500	2.48	6.23	14	592	7200	422	6.80	8.43	105	65.2	67.0	0.6
4	3500	[illegible]	7.41	15	681	5320	313	5.45	9.36	145	114	114	0.6
5	3500	12.1	10.0	15	862	5130	280	[illegible]	9.61	301	251	251	0.6
6	3500	.81	13.2	14	962	6200	—	—	—	—	—	—	—
7	3500	[illegible]	17.6	17	1009	7000	—	—	—	—	—	—	—
8	2500	7.67	7.20	21	685	7200	—	—	—	—	—	—	—
9	2500	[illegible]	5.54	24	[illegible]	8600	—	—	—	—	—	—	—
10	2500	—	4.80	25	966	28600	707	[illegible]	6.43	75.3	18.0	27.4	1.5
11	6000	0.60	11.0	12	[illegible]	1680	120	[illegible]	12.45	155	128	130	0.4
12	6000	9.32	15.0	19	[illegible]	3400	434	5.21	10.06	204	157	161	0.4
13	6000	18.6	20.0	21	[illegible]	3750	585	5.40	10.14	361	313	338	0.5
14	6000	27.9	23.4	22	1146	5000	609	6.39	9.35	316	242	242	0.4
15	6000	31.9	26.7	20	1206	[illegible]	925	6.55	9.83	358	288	288	0.4
16													
17	6000	33.1	18.9	23	1200	6000	2213	6.38	10.05	337	276	276	0.4
18	4000	28.4	21.7	22	1056	8100	705	7.19	8.66	317	239	252	0.7
19	4000	24.5	17.1	22	970	6400	1116	5.55	9.74	452	382	399	0.6
20	4000	20.8	15.7	25	1090	5650	516	5.16	10.07	475	404	434	0.6
21	4000	7.22	7.74	11	800	3600	215	2.31	11.52	281	240	240	0.6
22	4000	3.40	6.58	16	727	4020	172	3.29	10.87	176	129	49	0.6
23	4000	0.40	5.93	18	663	4850	202	4.93	9.80	125	82	85	0.5
24	5000	0.76	7.77	18	793	1600	175	2.09	11.97	232	186	191	0.4
25	5000	4.01	9.23	17	815	2600	564	2.65	11.37	324	235	235	0.4
26	5000	7.77	10.7	21	867	2480	172	2.82	11.25	357	344	344	0.4
27	5000	15.8	14.7	20	493	3700	213	4.24	10.16	503	425	425	0.4
28	5000	23.3	20.6	22	1114	4500	222	6.31	8.91	374	322	326	0.5
29	5000	27.8	24.0	25	1140	5400	201	6.78	8.61	330	279	279	0.6
30	5000	33.1	24.8	21	1038	5350	170	6.45	8.99	384	313	313	0.5
31													

Engine OMC ROTARY Run 4 Date 6/73 Barometer 29.16

Mode	rpm	Obs. Power, hp	Fuel, lb_m/hr	Temp., °F Int.	Temp., °F Exh.	FIA HC, ppmC	NDIR HC, $ppmC_6$	NDIR CO, %	NDIR CO_2 %	NDIR NO, ppm	C. L. NO, ppm	C. L. NO_x, ppm	Elect. O_2 %
1	IDLE	———	2.25	16	310	42000	2398	6.65	8.19	94.9	108	19.0	3.6
2	3500	0.18	5.24	12	535	8300	228	6.43	10.45	112	49	56	0.8
3	3500	3.05	6.21	19	588	7150	235	6.91	10.19	112	694	74	0.8
4	3500	5.96	7.09	23	674	5900	219	4.69	12.16	191	138	143	0.8
5	3500	12.3	10.0	11	844	5200	222	3.61	13.38	489	405	417	0.8
6	3500	17.7	13.3	14	929	6100	266	5.63	9.63	464	382	404	0.9
7	3500	25.1	18.0	25	1028	6250	233	6.78	8.61	287	244	253	0.9
8	2500	7.52	6.99	19	608	7850	303	7.00	8.86	113	111	112	0.9
9	2500	3.76	5.40	22	512	8900	345	7.46	8.46	66	61	63	0.9
10	2500	0.13	3.64	12	443	16000	445	6.74	8.00	47	28	36	1.3
11	6000	1.20	9.35	12	937	1080	86	1.54	12.18	239	201	202	0.5
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													

Engine OMC ROTARY Run 5 Date 7/73 Barometer 29.31

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. APTD-1496	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines Part 7: Snowmobiles		5. REPORT DATE April 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles T. Hare and Karl J. Springer		8. PERFORMING ORGANIZATION REPORT NO. AR-946
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwest Research Institute Vehicle Emissions Research Laboratory 8500 Culebra Road San Antonio, Texas 78284		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. EHS 70-108
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency 2565 Plymouth Road Ann Arbor, Michigan 48105		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report includes test data, documentation, and discussion on detailed exhaust emission characterization of four snowmobile engines (three two-stroke cycle and one rotary combustion cycle). It also covers the estimation of emission factors and national air quality impact. Broad regional and seasonal estimates of the distribution of these emissions are also made.

The exhaust products measured include HC, CO, CO_2, NO, O_2, light hydrocarbons, aldehydes, particulate, and smoke; SO_x emissions were calculated rather than measured. The engines were operated with steady-state "mapping" procedures using 20°F intake air.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 89
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)